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USAAEFA PROJECT NO. 77-11

FLIGHT EVALUATION
MK II INTEGRATED CONTROLLER INSTALLED IN AN OH-58A HELICOPTER

FINAL REPORT

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APRIL 1978

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UNITED STATES ARMY AVIATION ENGINEERING FLIGHT ACTIVITY
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The United States Army Aviation Engineering Flight Activity conducted a limited handling qualities and pilot workload evaluation of the MK II integrated controller installed in an OH-58A helicopter. The evaluation was conducted at Aberdeen Proving Ground, Maryland, from 8 November through 29 November 1977 and consisted of 22 flights for 15.2 hours of productive flight test time. The OH-58A could be safely flown throughout the recommended flight envelope using the integrated controller. The pilot workload when using the integrated controller with (over)

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20. Abstract

two hands was not reduced from and was sometimes greater than the workload when using ~~the~~ conventional controls for all maneuvers except level forward flight. Single hand control during flight and landing could be safely accomplished, but required increased pilot workload in all cases. The two most serious unsatisfactory characteristics identified were lack of an adequate system-decoupled warning and excessive workload during left sideward flight between approximately 15 to 25 knots true airspeed. Three unsatisfactory characteristics that contributed to the increased workload when using the integrated controller were excessive longitudinal and lateral integrated controller response and sensitivity, lack of control displacement harmony between the integrated controller cyclic and collective controls, and inadvertent cyclic control inputs with collective control movement. The reduced longitudinal and lateral control authority, which limited the aircraft's forward flight capability at aft center of gravity, rearward flight capability at forward center of gravity, and slope landing capability, was also an unsatisfactory characteristic. Eight additional unsatisfactory characteristics were identified during this evaluation.

(also)

DEPARTMENT OF THE ARMY
HQ, US ARMY AVIATION RESEARCH AND DEVELOPMENT COMMAND
P O BOX 209, ST. LOUIS, MO 63166

DRDAV-EQ

SUBJECT: Flight Evaluation MK II Integrated Controller Installed in an OH-58A Helicopter Final Report, AEFA Project No. 77-11

SEE DISTRIBUTION

1. The purpose of this letter is to establish the Directorate of Development and Engineering position on the subject report. This report covers a second evaluation of the concept, which incorporates four significant improvements, in the areas of handgrip design, mechanical method of decoupling, increased control authority and reduced control sensitivity about both the longitudinal and lateral axis.

2. This Directorate agrees with each conclusion stated in paragraph 46 through 51 of the report. All the changes mentioned above, did improve the flying qualities. Regarding paragraph 51.1, the unsatisfactory characteristics of the integrated controller with the hydraulic boost inoperative is considered serious. The excessive forces developed appears to result from a poor mechanical advantage which is not exhibited with the standard helicopter flight controls which may well be an inherent problem. It is also interesting to note the substantial agreement between the two test pilots which is presented in their Qualitative Workload Assessment of Table 3, paragraph 41. In no case did their HQRS vary by more than one. Except for maintaining steady level flight, the rating was usually higher (greater workload) with the integrated controller than for flight with conventional controls. Because of this and other control limitations, further effort with this integrated controller does not appear warranted.

3. The recommendation contained in paragraph 52 through 56 were incorporated in the Airworthiness Release issued for user pilot demonstrations.

4. No further participation in the program by AVRADCOM is invisioned.

FOR THE COMMANDER:

WALTER A. RATCLIFF
Colonel, GS
Director of Development
and Engineering

PREFACE

The test program was conducted at Aberdeen Proving Ground (APG), Maryland. Test aircraft maintenance was provided by Ross Aviation. The chase aircraft was provided by Phillips Army Airfield Flight Detachment, APG. Crash rescue support was provided by the Fire Prevention and Protection Division, APG, and Headquarters Company, Fort Meade, Maryland. These personnel provided superior support and were a significant factor in the safe and expeditious conduct of the program.

Contributions of personnel of the United States Army Human Engineering Laboratory, APG, are acknowledged for their professionalism and dedication during the conduct of the test program.

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INTRODUCTION

BACKGROUND

1. The United States Army Human Engineering Laboratory (USAHEL), Aberdeen Proving Ground (APG), Maryland, has been exploring the feasibility of combining helicopter conventional cyclic and collective controls into a single integrated controller capable of being operated by either hand alone during all phases of helicopter flight. The design objectives of the integrated controller system are to provide the pilot a free hand to operate aircraft subsystems, reduce cockpit complexity, reduce training requirements, and enhance aircraft and aircrew survivability. An integrated controller system was designed and fabricated by USAHEL and initially installed and evaluated on a ground flight simulator (ref 1, app A). The integrated controller was later installed in an OH-58A helicopter and was evaluated by the United States Army Aviation Engineering Flight Activity (USAAEFA) (ref 2). As a result of this evaluation, modifications were made to the integrated controller. The United States Army Aviation Systems Command (AVSCOM)* directed USAAEFA to conduct flight testing of the modified (MK II version) integrated controller system (ref 3).

TEST OBJECTIVES

2. The objectives of this flight test program were as follows:

a. Conduct flight tests to provide data to substantiate an airworthiness release for subsequent human factors flight evaluations using the MK II integrated controller installed in an OH-58A helicopter.

b. Conduct a qualitative and quantitative evaluation to determine the feasibility of the integrated controller concept with respect to pilot workload for normal and emergency flight conditions.

DESCRIPTION

3. The integrated controller combines conventional cyclic and collective controls into a single device (photo A). It consists of a vertical column, hinged at the bottom, which when pulled toward the pilot increases collective pitch and when pushed away from the pilot decreases collective pitch. Two handgrips, one located on either side of the vertical column near the top, provide pitch and roll control. When rotated about a lateral axis through its center, either handgrip controls the pitch attitude of the aircraft. As the top of the grip is rotated forward, a nose-down

*Since redesignated United States Army Aviation Research and Development Command (AVRADCOM).

pitch control is applied to the aircraft; with aft rotation, a nose-up pitch control. When rotated about a longitudinal axis through its center, either handgrip controls the roll attitude of the aircraft. As the top of the grip is rotated left, a left roll control is applied to the aircraft; with right rotation, a right roll control. The MK II integrated controller differed from the earlier version in these five areas:

a. Handgrips were redesigned.

b. Electromechanical decoupling units replaced override control springs.

c. Longitudinal and lateral control stops were changed to increase control authority.

d. Lateral control sensitivity was decreased.

e. Longitudinal control sensitivity was decreased.

A more detailed system description is presented in appendix B.

4. The integrated controller system was installed in place of the copilot conventional cyclic and collective controls in an OH-58A aircraft. The test aircraft, SN 71-20380, was a standard aircraft except for the installation of the integrated controller system and an instrumentation system (app C). A more detailed description of the OH-58A helicopter is presented in the operator's manual (ref 4, app A).

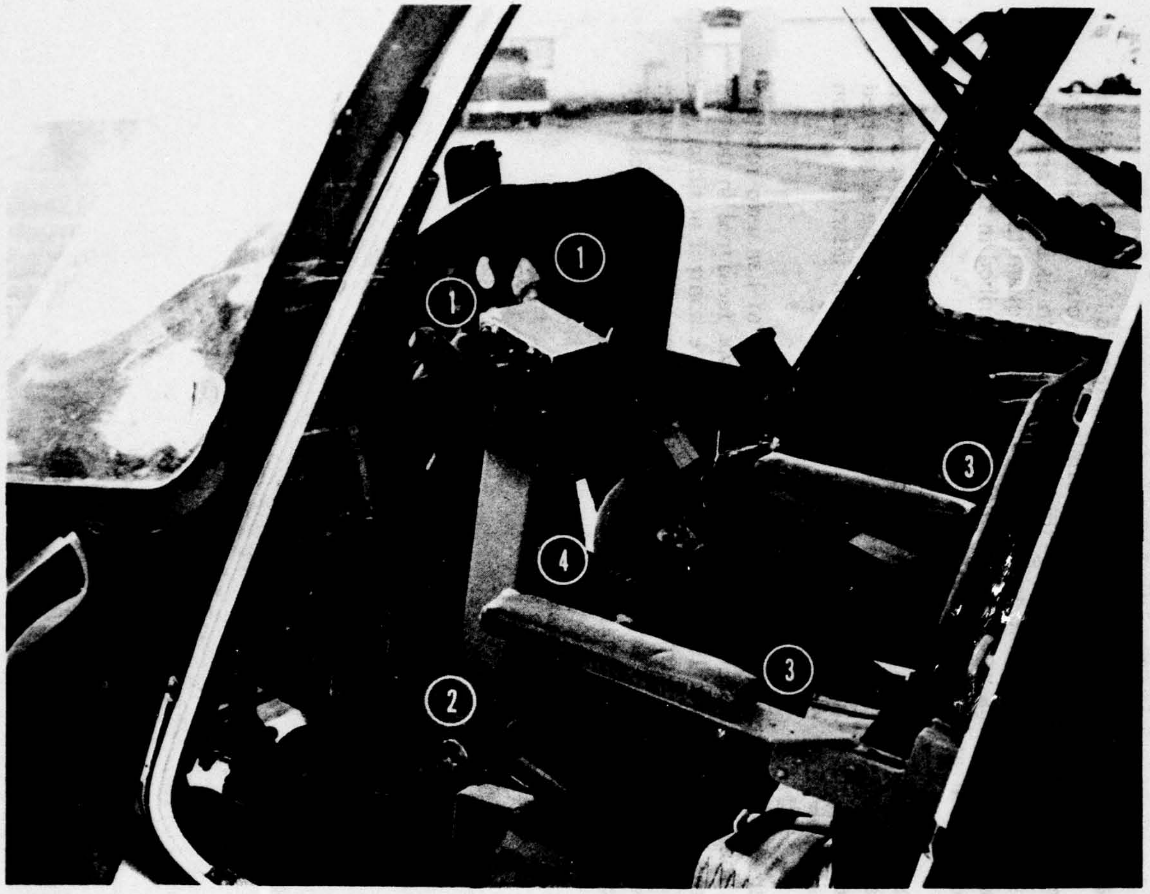
TEST SCOPE

5. The flight evaluation of the MK II integrated controller installed in an OH-58A aircraft was conducted by USAAEFA at APG between 8 November and 29 November 1977. Testing consisted of 15.2 hours of productive flight test time which was obtained during 22 flights and 19.9 total flight hours. The limitations of the airworthiness release (ref 5, app A) were observed throughout the testing. Testing was conducted in accordance with the USAAEFA test plan (ref 6). The general test conditions are presented in table 1. Portions of the test results were analyzed with respect to previous USAAEFA tests (refs 2 and 7).

6. Maintenance support for the test aircraft was provided by Ross Aviation. The integrated controller was installed and maintained by USAHEL and Ross Aviation personnel. Flight test instrumentation was installed and maintained by USAAEFA personnel.

TEST METHODOLOGY

7. During the handling qualities portion of the testing, established flight test techniques and data reduction procedures were used (ref 8, app A). The test



1. Cyclic control handgrips.
2. Auxiliary collective friction adjustment.
3. Folding arm rests.
4. Collective control column.

Photo A. Integrated Controller.

methods are briefly discussed in the Results and Discussion section and appendix D of this report. A Handling Qualities Rating Scale (HQRS) (app D) was used during the evaluation to assist in qualitative assessment of the integrated controller.

8. A qualitative workload comparison between the integrated controller and the conventional controls was made while performing numerous standard flight maneuvers. The HQRS was used during this comparison to assist in assessing differences in workload between the two control systems. A quantitative analysis of the comparative workloads was also conducted and is described in the Results and Discussion section and appendix D.

9. Test data were hand-recorded from cockpit instruments and were recorded on magnetic tape installed in the aircraft. Real-time telemetry monitoring of selected data parameters was used during the testing. A detailed list of instrumentation is presented in appendix C.

10. Longitudinal control position was measured in degrees of handgrip rotation from the full forward position. Lateral control position was measured in degrees of handgrip rotation from the full left position. Collective control position was measured in degrees of control column rotation from the full forward (minimum collective) position. The integrated controller positions in degrees were directly related to the conventional control positions in inches.

Table 1. General Test Conditions.[1]

Test	Average Gross Weight (lb)	Average Center-of-Gravity Location[2] (in.)	Average Density Altitude (ft)	Average Trim Calibrated Airspeed (kt)	Flight Condition
Control positions in trimmed forward flight	2880	106.8 (fwd)	840	81 to 118	Level
	2960	111.2 (aft)	2440	33 to 107	
Maneuvering stability	2820	106.3 (fwd)	1080	103	Constant airspeed, fixed collective control turns
	2900	111.1 (aft)	2360	63 and 102	
Controllability	2860	106.7 (fwd)	-1820	Zero	Hover
	2830	111.0 (aft)	-460		
	2840	106.7 (fwd)	950	66 and 99	Level
	2950	111.2 (aft)	1000	64 and 100	
Low-speed flight	2850	106.6 (fwd)	-1240	30 rwd to 35 fwd[3]	Level
	2940	111.2 (aft)	-760	35 left to 35 right[3]	
Mission maneuvers	2800 to 3000	107.1 (fwd)	-760 to 3000	Zero to 118	---
		109.1 (mid)			
		111.2 (aft)			
Simulated engine failure	2800	106.3 (fwd)	1100	66 and 99	Level flight entry
	2900	111.1 (aft)		64 and 100	
Workload evaluation	2940	109.0 (mid)	300 to 3000	58 to 102	Level, climb and descent
	2960	109.2 (mid)	-750	Zero	Hover
	2940		400 to 2800	61	Autorotation
	2960	109.2 (mid)	-750 to 3000	Zero to 100	Hydraulics OFF
	2800 to 3000	109.1 (mid)		Zero to 118	Maneuvering

[1]Rotor speed: 354 rpm.
[2]Average lateral center-of-gravity (cg) location: 0.3 inch right.
[3]True airspeed.

RESULTS AND DISCUSSION

GENERAL

11. A limited handling qualities and pilot workload evaluation of the MK II integrated controller installed in an *OH-58A helicopter* was conducted by USAAEFA. The handling qualities portion of the evaluation was conducted near both the forward and aft cg limit and close to maximum gross weight. The aircraft could be safely flown throughout the recommended flight envelope using the integrated controller; however, this envelope is reduced from the standard OH-58A envelope. The reduced cyclic control authority of the integrated controller limited forward flight capability at an aft cg, rearward flight capability at a forward cg, and slope landing capability of the aircraft. Except for the reduced control authority when the integrated controller was coupled, the conventional controls at the pilot station operated normally during all flight operations. During the evaluation, the workload while flying the integrated controller with both hands was not reduced and was sometimes greater than the workload while using the conventional controls for all maneuvers except level forward flight. Flight and landing using single hand operation of the integrated controller could be safely performed but required increased pilot workload in all cases. The two most serious unsatisfactory characteristics identified were: lack of an adequate system-decoupled warning and excessive workload during left sideward flight between approximately 15 to 25 knots true airspeed (KTAS). Three unsatisfactory characteristics which contributed to the increased pilot workload when using the integrated controller were excessive longitudinal and lateral integrated controller response and sensitivity, lack of control displacement harmony between the integrated controller cyclic and collective controls, and inadvertent cyclic control inputs with collective control movement. The reduced longitudinal and lateral control authority was an unsatisfactory characteristic which reduced the capability of the aircraft. Eight additional unsatisfactory characteristics were identified.

HANDLING QUALITIES

Control System Characteristics

Position Characteristics:

12. Position characteristics of the integrated controller were measured on the ground with the rotors and engine stopped. Hydraulic and electrical power were provided by an external source. Longitudinal and lateral rotational positions of the integrated controller handgrips were measured in degrees about a center of rotation at approximately the midpoint of either handgrip. The longitudinal zero degree position was with the top of the handgrip rotated to its maximum forward extent and the lateral zero degree position was with the top of the handgrip rotated to its maximum left extent. The full-throw longitudinal and lateral integrated

control pattern is shown in figure 1, appendix E. Longitudinal and lateral control limits were independent of collective position. The relationship between the integrated controller pattern and the conventional cyclic pattern is shown in figure 2. With the lateral control positioned at approximately mid-travel, the integrated controller longitudinal rotational throw was 72 degrees, which corresponds to 9.7 inches or 81 percent of conventional longitudinal cyclic full throw. With the longitudinal control positioned at approximately mid-travel, the lateral rotational throw of the integrated controller was 58 degrees, which corresponds to 6.8 inches or 66 percent of conventional lateral cyclic full throw. The reduction in the cyclic control authority reduced the longitudinal and lateral control margin of the aircraft. The reduced longitudinal and lateral control authority limited the forward flight (para 20), slope landing (para 25), and rearward flight (para 27) capabilities of the aircraft and is unsatisfacotry.

13. The integrated controller collective control position was measured in degrees about the hinge point at the base of the control column. The zero degree position was with the column full forward (minimum pitch setting). Collective control full throw was 20 degrees, which corresponds to 10.3 inches or 100 percent of conventional collective full throw.

14. The difference in method and size of control displacements between the integrated controller collective control column and cyclic control handgrips was objectionable during flight. The collective control required a large upper-arm push-pull movement over a maximum 8 1/2-inch displacement. In contrast, the cyclic controls required a small, precise wrist rotation through a maximum of 72 degrees longitudinally and 58 degrees laterally. In flight, the collective motion required always felt excessive and not in harmony with the smaller cyclic control movements. This difference was most noticeable during maneuvers requiring large collective movements such as vertical takeoffs or landings, accelerations or decelerations, and initiation of climbs or descents. The lack of control displacement harmony between the integrated controller cyclic and collective controls degraded aircraft control and is unsatisfactory.

Force Characteristics:

15. Force characteristics of the integrated controller were measured on the ground with rotors and engine stopped. Hydraulic and electrical power were provided by an external source; the flight control force trim system was ON and control friction was OFF. The forces were applied longitudinally and laterally at points near the top of one handgrip and were expressed as moments (inch-pounds). The variation of control input torque with rotational position is shown in figures 3 and 4, appendix E, for the longitudinal and lateral controls, respectively. A summary of the measured control moment characteristics is shown in table 2. No control position free play was observed in the integrated controller system. Control gradients were positive and essentially linear. The variation in breakout force (including friction) and average torque gradient near trim between the longitudinal and lateral controls was not objectionable in flight. Control centering characteristics were adequate.

Table 2. Moment Characteristics Summary.

Item	Longitudinal Control		Lateral Control	
	Forward	Aft	Left	Right
Breakout including friction (in.-lb)	10.0	7.0	Zero	4.0
Average torque gradient near trim (in.-lb/deg)	0.10	0.30	0.76	0.32
Average friction band near trim (in.-lb)	14.0	12.5	15.0	8.0
Centering	Positive	Absolute	Positive	Positive

16. Control moment characteristics were qualitatively validated in flight. The moments required in flight appeared to be less than those required during the ground evaluation. This was because the hand produces a force couple to provide the rotational moment of the handgrip as opposed to the single, moment-producing force applied during the ground evaluation. For example, during a forward longitudinal cyclic control input the top part of the hand pushes forward on the upper portion of the handgrip while the lower fingers pull aft on the lower portion. The force distribution of the couple effectively reduced the pilot's required control effort in flight. The use of two hands on the handgrips further distributed the required forces and reduced pilot effort. The longitudinal and lateral control moment characteristics of the integrated controller system are satisfactory.

17. A force trim release button was conveniently located beneath the thumb position on each handgrip. Negligible cyclic control jump was observed when releasing the force gradient following accelerations and decelerations between zero and 90 knots indicated airspeed (KIAS). The dynamic reaction of the handgrips to an inadvertent bump or release against the force gradient was deadbeat. The dynamic characteristics of the integrated controller cyclic handgrips are satisfactory.

18. The force characteristics of the integrated controller collective control were measured on the ground under conditions similar to those described in paragraph 14. From a midpoint collective setting, 5 pounds of pull force were required to initiate and maintain an increasing collective control motion and 1 pound of push force was required to initiate and maintain a decreasing motion. The differential force requirements of the opposing push and pull motions were not objectionable with a small amount of collective control friction applied and the force characteristics of the integrated controller collective control are satisfactory.

Decoupled Operation:

19. The decoupling system (para 12, app B) was designed to give the safety pilot an override capability. The safety pilot could activate the decouplers at any time and isolate the integrated controller from the remainder of the flight control system. The set of conventional cyclic and collective controls on the right side of the aircraft returned to full conventional control authority when the integrated controller was decoupled. Except for the reduced control authority when the integrated controller was coupled, the conventional controls operated normally during all flight operations.

Control Positions in Trimmed Forward Flight

20. Integrated controller characteristics during trimmed forward flight were evaluated from 31 to 118 knots calibrated airspeed (KCAS) at the conditions shown in table 1. The variation of control position and pitch attitude with airspeed is shown in figures 5 and 6, appendix E. Establishing and maintaining a specific airspeed required less pilot compensation than with the conventional controls (HQRS 2). Hand and arm positions were comfortable throughout the tested airspeed range at both forward and aft cg configurations. Control margins at all airspeeds in the forward cg configuration exceeded 10 percent and were satisfactory. Less than 10 percent forward longitudinal control margin remained at airspeeds greater than 100 KCAS in the aft cg configuration. Sufficient control margin may not be available above 100 KCAS at the aft cg condition to correct for nose-up pitch disturbances in gusty wind conditions. Therefore, the aircraft in the aft cg configuration should be restricted from forward flight airspeeds in excess of 100 KCAS when the integrated controller is coupled into the flight control system.

Maneuvering Stability

21. Integrated controller characteristics were evaluated at the conditions shown in table 1 while performing left and right steady-state turns with force trim ON. Steady-state turns were conducted by establishing the desired level flight airspeed and stabilizing at increasing bank angles while maintaining collective control and airspeed constant. The variation of integrated controller cyclic control positions with cg normal acceleration is shown in figures 7 and 8, appendix E. The increasing aft longitudinal control position required with increasing cg normal acceleration provided weak but adequate force and position cues to the pilot. Hand and arm positions were comfortable at all bank angles and airspeeds tested. Pilot compensation required to establish and maintain bank angles up to 45 degrees at constant airspeed with the integrated controller was slightly greater than with conventional controls (HQRS 4). A lateral pilot-induced oscillation caused small bank angle oscillations. Bank angles greater than 45 degrees required even greater pilot compensation to control increased pitch and roll oscillations (HQRS 5). The lateral pilot-induced oscillation during turning flight is unsatisfactory.

Controllability

22. Controllability tests using the integrated controller were conducted at the conditions shown in table 1. Step control inputs of varying size were made in the longitudinal and lateral axes using the integrated controller handgrips. Input size was gauged by a hand-held control fixture on the conventional cyclic control. Test results are shown in figures 9 through 14, appendix E. Because of the rotational motion used by the integrated controller for cyclic control and the short control arms about the point of rotation, an extremely small longitudinal or lateral control input produced an unexpectedly large aircraft response. For example, the control response and sensitivity produced by a 1-inch conventional longitudinal cyclic input required only a 7.2-degree rotation of the integrated controller handgrip. This rotation was equivalent to approximately 0.3 inch of movement at the top of the handgrip. Control response and sensitivity observed during this evaluation were generally lower than that reported during the evaluation of the initial integrated controller design (ref 2, app A) but were still excessive. The oversensitive longitudinal and lateral controls degraded aircraft attitude control and increased pilot workload during all flight maneuvers except level forward flight. Increased overcontrol and pilot-induced oscillation tendencies were observed during precision tasks such as hover, takeoff, landing, and nap-of-the-earth (NOE) flight. The excessive longitudinal and lateral integrated controller response and sensitivity are unsatisfactory.

Takeoff and Landing Characteristics

23. Takeoff and landing characteristics using the integrated controller were evaluated throughout the test program. Normal, steep angle, and running takeoffs and landings were performed at forward, mid, and aft cg conditions. All the maneuvers were safely conducted using the integrated controller but required greater pilot workload (HQRS 4) than the conventional controls to maintain the desired flight path angle and aircraft acceleration or deceleration. Two specific control difficulties were observed which contributed to the increased workload requirement. First, inadvertent longitudinal cyclic control motions were input by the pilot when collective movements were made. Collective reductions caused nose-up cyclic inputs and collective increases caused nose-down cyclic inputs. These inadvertent cyclic control inputs with collective control movement caused undesired airspeed variations (±5 to 10 knots) and are unsatisfactory. Secondly, lateral pilot-induced oscillations were noted during climb-out following a takeoff and during approach prior to a landing. These lateral pilot-induced oscillations during climb-out and approach were small (±3 to 5 degrees) but were distracting to the pilot, increased control workload, and are unsatisfactory.

24. Vertical takeoffs to a hover and landings from a hover using the integrated controller were evaluated at forward, mid, and aft cg conditions. These maneuvers were extremely difficult to perform initially and required extensive pilot compensation to maintain a vertical flight path over a selected point on the ground (HQRS 6). The aircraft tended to translate forward because the pilot would not maintain sufficient aft longitudinal cyclic control while pulling the collective control

aft. This situation was aggravated at the forward cg condition. Following approximately 3 flight hours on the integrated controller, pilot familiarization and accommodation with the aft longitudinal cyclic motion requirement reduced the pilot workload levels (HQRS 3) and these maneuvers could be satisfactorily performed.

Slope Landing Characteristics

25. Slope landing and takeoff characteristics using the integrated controller were evaluated at forward, mid, and aft cg conditions. Landings and takeoffs on left and right slopes up to approximately 7 degrees were evaluated. Slope angles were measured in terms of aircraft roll attitude using the standard aircraft attitude indicator. The high lateral cyclic control sensitivity (para 22) degraded precise roll control of the aircraft during these maneuvers (HQRS 4). Left and right cyclic control limits were intermittently reached at approximately 6 to 7 degrees right and left slope respectively. On slopes of 5 degrees or less, landings and takeoffs could be safely performed. When the integrated controller is coupled into the flight control system the aircraft should be restricted from landings and takeoffs on slopes steeper than 5 degrees.

Low-Speed Flight Characteristics

26. Flight characteristics using the integrated controller were evaluated while performing low-speed forward, rearward, and sideward flight at the conditions shown in table 1. The purpose of these tests was to determine control margins and control characteristics while hovering in various wind conditions. A ground pace vehicle was used as an airspeed reference. Low-speed flight test results are presented in figures 15 through 18, appendix E.

27. At the aft cg condition, adequate integrated controller margins remained throughout the tested airspeed range during both sideward and low-speed forward and rearward flight. At the forward cg condition, the minimum longitudinal integrated controller margin was 2 degrees (3 percent) aft longitudinal control remaining during rearward flight at 12 KTAS (fig. 15, app E). At this test condition, the aft longitudinal integrated controller limit was intermittently reached. Attempts to attain a higher rearward airspeed were unsuccessful and sufficient control margin was not available to correct for nose-down pitching caused by gusts. When the integrated controller is coupled into the flight control system and the aircraft is in a forward cg condition, the aircraft should be restricted from rearward flight in excess of 10 KTAS or hovering in comparable wind conditions.

28. During left sideward flight at both cg conditions, directional instability was observed between approximately 15 to 25 KTAS. This instability problem has been identified on previous flight tests of the OH-58A (ref 7, app A). During this evaluation, directional instability was characterized by rapid, strong yaw reversals of the aircraft. Heading control could not be maintained as 15 KTAS left sideward flight was approached and the aircraft would yaw nose-into the relative wind. At left sideward airspeeds of 10 KTAS and below, this problem was not noted.

Although this characteristic is not directly related to the integrated controller installation, the combined workload requirements of the directional control and integrated cyclic control were excessive and saturated the pilot's capability (HQRS 7). This excessive workload during left sideward flight between approximately 15 to 25 KTAS will present a hazardous situation when hovering the aircraft in confined areas during gusty wind conditions and is unsatisfactory. The aircraft should be restricted from left sideward flight in excess of 10 KTAS or hovering in comparable wind conditions when using the integrated controller.

29. While evaluating hovering flight at a forward cg condition using the integrated controller, the aft rotational position of the longitudinal cyclic handgrips required for a stable hover was extremely uncomfortable and fatiguing to the pilot. In this flight condition, the upward rotation limit of the pilot's wrists was being approached. This adverse situation was aggravated during tail wind conditions or rearward flight where additional aft cyclic handgrip rotation was required. To provide this additional control movement, the pilot was required to remove his elbows from the armrests and lower his shoulders and upper body, which resulted in degraded aircraft attitude and position control. The excessive aft rotational position of the longitudinal cyclic handgrips while hovering at a forward cg condition is unsatisfactory.

Mission Maneuvering Characteristics

30. Aircraft control characteristics were qualitatively evaluated while performing typical mission maneuvers using the integrated controller. The maneuvers performed were NOE flight, accelerations, decelerations, bob-ups, and pop-ups. These maneuvers were evaluated at forward, mid, and aft cg conditions. All of these maneuvers were safely performed using the integrated controller; however, attitude, airspeed, and altitude control were degraded compared to using the conventional controls. The high lateral and longitudinal control sensitivity (para 22) and the inadvertent cyclic control inputs with collective movement (para 23) contributed to the degraded control characteristics when using the integrated controller.

Hydraulic System Failure

31. Aircraft control characteristics using the integrated controller with the hydraulic boost turned off were qualitatively evaluated at forward, mid, and aft cg conditions. Typical flight maneuvers consisting of level flight, climbs, descents, turns, hovering flight, and running landings were performed. These maneuvers were all safely performed using the integrated controller. The short length of the cyclic control handgrip greatly magnified the pilot effort required during these maneuvers in comparison to the conventional controls. Extensive pilot effort was required to adequately control the aircraft in the presence of these excessive forces (HQRS 6). The excessive cyclic control force required with hydraulic boost OFF is unsatisfactory.

Autorotational Entry and Descent

32. Aircraft control characteristics while using the integrated controller were qualitatively evaluated while performing autorotational entries and descents at forward and aft cg conditions. Since the only throttle in the cockpit is located on the pilot conventional throttle control, rapid throttle reductions were accomplished by the safety pilot. The evaluation pilot, using the integrated controller, held controls fixed for 2 seconds or until a minimum main rotor speed of 330 rpm was attained. He then manipulated the controls as necessary to establish stable autorotational descent at 60 KIAS and normal rotor speed.

33. Following rapid throttle reductions in level forward flight at 60 and 100 KIAS, transition to stable autorotational descent was easily and safely accomplished (HQRS 2). Main rotor speed control was satisfactory.

34. During the stabilized autorotational descent following each entry, the collective control was positioned full forward to maintain main rotor speed. This forward position of the control column and cyclic handgrips required the pilot to fully extend his arms and lose elbow contact with the armrests. Moderate pilot effort was initially required to maintain a level bank attitude and the desired airspeed (HQRS 4). Small-amplitude (±2 to 3 degrees in pitch) longitudinal pilot-induced oscillations were also observed during the descents. As the descent continued, the extended arm position became increasingly fatiguing and aircraft attitude control was further degraded. The excessive forward position of the control column during autorotational descent is unsatisfactory.

Single Hand Control

35. Flying the test aircraft with the integrated controller was normally conducted during this evaluation by using both hands on the controller handgrips. In addition, however, sufficient right and left single-hand operation of the controller was conducted to qualitatively determine if the aircraft could be safely flown and landed using either hand alone. When compared to two-hand control, pilot workload using single-hand control was greater and aircraft attitude control was degraded in all cases. Two adverse factors of single-hand control were noted. There was an effective increase in control forces when the single hand was providing the total control input, and the absence of the damping action which one arm and hand provided the other in two-hand operation resulted in increased pilot-induced oscillation tendencies. However, the aircraft was safely flown and landed with a single hand.

SYSTEM INTEGRATION

36. The functional adaptability of the integrated controller system was qualitatively evaluated throughout the test program. The size and shape of the controller handgrips provided a comfortable and natural hand position. The location of the force trim release switches and radio/intercom switches allowed easy operation. Except for the excessive aft longitudinal cyclic rotation position under certain flight conditions (para 29), the handgrips installed on the integrated controller were satisfactory.

37. The integrated controller system did not provide an adequate system-decoupled warning to the pilots to alert them when the integrated controller became decoupled from the aircraft control system. This situation could occur by inadvertent activation of the decouple switch on the conventional cyclic control stick or by interruption of electrical power to the integrated controller decoupling system. A prominent warning is necessary so that the safety pilot can immediately assume control of the aircraft. The lack of an adequate system-decoupled warning is unsatisfactory.

38. Depressing the trigger switch on the conventional cyclic control decoupled the integrated controller. However, the decoupler units would not decouple the integrated controller from the flight controls in any of the axes where opposing control forces were present. For example, if the integrated controller pilot was applying a nose-down longitudinal force and the safety pilot was applying a nose-up force, the system would not decouple the longitudinal cyclic control. To obtain a decouple, the safety pilot had to input a control pulse in the opposite direction of his applied force to relieve the opposing control forces. The decoupling system is for use in emergency situations where the safety pilot must rapidly assume control of the aircraft and it should immediately operate when activated. The inability to decouple the integrated controller system when opposing control forces are present is unsatisfactory. The following CAUTION should be incorporated into the integrated controller operating procedures:

CAUTION

> The integrated controller will not decouple in axes where opposing control forces between the integrated controller and conventional controls are present.

39. When exiting the left seat, the pilot's right foot and boot were frequently caught on portions of the instrument panel, integrated controller column, or control tube shield. The left-seat pilot's egress was hampered by the careful attention necessary to remove his right leg and foot from between the control column and instrument panel. The restricted cockpit egress from the left seat is unsatisfactory.

40. During most flight maneuvers, the coupler status panel and left-seat pilot communication system control (C6533/ARC) was masked from the left-seat pilot's view by the integrated controller column and grip assembly. Both of these panels are frequently referred to in flight. The left-seat pilot was required to shift his head laterally to the right to see these panels. The location of these two panels is unsatisfactory.

WORKLOAD EVALUATION

41. A comparative evaluation of pilot workload while performing various steady-state and dynamic flight maneuvers was conducted using the integrated controller and the conventional controls. Two pilots flew the same set of flight

maneuvers using first the conventional controls and then the integrated controller. The evaluations of the conventional controls and integrated controller by each individual pilot were flown on immediately successive flights to obtain comparable weather conditions. The integrated controller was flown using two-hand operation throughout the workload evaluation flights. In general, it was observed that workload for the integrated controller was equal to or greater than the workload for the conventional controls except in level forward flight, where workload was reduced. The integrated controller concept is feasible in that all the evaluated maneuvers could be performed using the integrated controller.

42. Dynamic flight maneuvers consisted of bob-ups, pop-ups, rapid accelerations and decelerations, NOE flight, autorotational entries, and hydraulics OFF landings. Pilot workload for these maneuvers was qualitatively assessed using the HQRS. The performance of these maneuvers has been previously discussed in the Handling Qualities section of this report. Workload for autorotational entries was minimal (HQRS 2) for both controls (para 33). The mission maneuvers (bob-ups, pop-ups, accelerations, decelerations, and NOE flight) required increased pilot compensation when using the integrated controller (HQRS 4) as compared to the conventional controls (HQRS 3). The high cyclic sensitivity and inadvertent cyclic inputs with collective movement contributed to the increased workload of the integrated controller (para 30). During the performance of hydraulics OFF landings, pilot compensation required with the integrated controller (HQRS 6) was significantly higher than with the conventional controls (HQRS 4). The short cyclic control arm of the integrated controller greatly increased the control forces required to maintain level pitch and roll attitude during the maneuver while using the integrated controller (para 31).

43. The steady-state flight maneuvers performed are shown in table 3 with each pilot's qualitative assessment of the workload for each maneuver using the conventional controls and integrated controller. The maneuvers were flown in visual meteorological conditions (VMC) using two hands on the integrated controller. The following tolerances were used as guides within which the given flight parameter was maintained: ±5 knots airspeed, ±50 feet altitude, ±50 feet per minute (ft/min) rate of climb or descent, ±5 degrees heading, ±3 degrees bank angle, ±1 foot hover height and ±3 feet horizontal hover position. In level forward flight, the control of aircraft pitch attitude and airspeed appeared to be slightly easier using the integrated controller. In all other maneuvers, workload using the integrated controller was not reduced and was sometimes greater than with the conventional controls.

44. In an attempt to quantify the differences in workload between the integrated controller and conventional controls, various statistical analyses (as described in app D) were performed on time history data recorded during the steady-state maneuvers. This data consisted of control positions, aircraft angular attitudes and rates, airspeed, and altitude. The integrated controller control position data were recorded in degrees of rotation and were converted to inches of movement of the conventional controls for the purposes of comparison and statistical computation. The results of these analyses were not consistent and did not

Table 3. Qualitative Workload Assessments.

Steady-State Maneuver	Workload Assessment Rating (HQRS)			
	Pilot 1		Pilot 2	
	Conventional Controls	Integrated Controller	Conventional Controls	Integrated Controller
Level flight, 60 KIAS	3	2	3	2
Level flight, 100 KIAS	3	2	3	2
Climb, 500 ft/min, 60 KIAS	3	3	2	3
Climb, 1000 ft/min, 60 KIAS	3	3	2	3
Descent, 500 ft/min, 60 KIAS	3	3	2	3
Descent, 1000 ft/min, 60 KIAS	3	3	2	4
Autorotation, 60 KIAS	2	4	3	4
Turns, standard rate left and right, 60 KIAS	3	4	3	3
Turns, standard rate left and right, 100 KIAS	3	4	3	3
Hover, headwind[1]	3	4	3	4
Hover, tailwind[1]	3	5	3	4
Level flight, 60 KIAS, hydraulics OFF	4	5	3	4
Level flight, 100 KIAS, hydraulics OFF	4	5	3	4

[1]Approximately 12 to 15 knots.

uniformly correlate with pilot qualitative assessments. Therefore, the pilot's qualitative assessments alone were used to comparatively evaluate workload between the integrated controller and conventional controls.

45. The failure of the statistical analyses to provide workload data which consistently correlated with pilot qualitative assessments could not be attributed to a single specific cause. The following factors may have contributed to the inconsistencies in the statistical data and the differences between the data and the pilot qualitative assessments:

a. The differences in pilot qualitative assessment ratings between the integrated controller and the conventional controls were small. Therefore, the actual differences in parameters being measured were probably quite small. This could have resulted in an overlap of the measurement error band for the same parameter on the conventional controls. The overlap would cause inconsistencies in the data and preclude conclusive results.

b. The cyclic control movement required with the integrated controller consisted of longitudinal and lateral wrist rotation utilizing primarily lower arm muscles. This movement was significantly different from that required for the conventional cyclic control, which consisted of lateral and longitudinal horizontal movement utilizing different muscle motions. The fore and aft longitudinal movement for the integrated controller collective was also different from the basically up and down motion for the conventional collective control. These differences may have contributed to higher handling qualities ratings for maneuvers using the integrated controller as compared to maneuvers using the conventional controls. The HQRS assessments, which are subjective in nature, may have reflected an increased coordination workload because of the evaluation pilot's lack of extensive experience with the motor responses required for the integrated controller. In this situation, however, the quantitative data would not necessarily show a significant difference between the two control systems.

CONCLUSIONS

46. The OH-58A helicopter can be safely flown throughout the recommended flight envelope using the integrated controller system; however, this envelope is reduced from the standard OH-58A envelope (para 11).

47. During the performance of all tested flight maneuvers except level forward flight, pilot workload requirement when using the integrated controller with two hands was not reduced and was sometimes greater than when using the conventional control (para 43).

48. The aircraft could be safely flown and landed using single-hand operation of the integrated controller; however, pilot workload requirements were increased in all cases when compared to two-hand operation (para 35).

49. Except for the reduced control authority when the integrated controller was coupled, the conventional controls operated normally during all flight operations (para 19).

50. The short length of the integrated controller cyclic control handgrip magnified the pilot effort required during flight with hydraulic boost OFF when compared to the conventional controls (para 31).

51. The following unsatisfactory characteristics were noted and are listed in decreasing order of importance:

a. Lack of an adequate system-decoupled warning (para 37).

b. Excessive workload during left sideward flight between approximately 15 to 25 KTAS (para 28).

c. Excessive longitudinal and lateral integrated controller response and sensitivity (para 22).

d. Reduced longitudinal and lateral control authority (para 12).

e. Lack of control displacement harmony between the integrated controller cyclic and collective controls (para 14).

f. Indavertent cyclic control inputs with collective control movement (para 23).

g. Inability to decouple the integrated controller system when opposing control forces are present (para 38).

h. Excessive aft rotational position of the longitudinal cyclic handgrips while hovering at a forward cg condition (para 29).

i. Excessive forward position of the control column during autorotational descent (para 34).

j. Lateral pilot-induced oscillations during turning flight (para 21).

k. Lateral pilot-induced oscillations during climb-out and approach (para 23).

l. Excessive cyclic control force required with hydraulic boost OFF (para 31).

m. Location of the coupler status panel and left seat pilot communications system control (para 40).

n. Restricted cockpit egress from the left seat (para 39).

RECOMMENDATIONS

52. The aircraft should be restricted from left sideward flight in excess of 10 KTAS or hovering in comparable wind conditions when using the integrated controller (para 28).

53. The aircraft in the aft cg configuration should be restricted from forward flight airspeeds in excess of 100 KCAS when the integrated controller is coupled into the flight control system (para 20).

54. When the integrated controller is coupled into the flight control system the aircraft should be restricted from landings and takeoffs on slopes steeper than 5 degrees (para 25).

55. When the integrated controller is coupled into the flight control system and the aircraft is in a forward cg condition, the aircraft should be restricted from rearward flight in excess of 10 KTAS or hovering in comparable wind conditions (para 27).

56. The follwoing CAUTION should be incorporated into the integrated controller operating procedures (para 38).

CAUTION

The integrated controller will not decouple in axes where opposing control forces between the integrated controller and conventional controls are present.

APPENDIX A. REFERENCES

1. Technical Memorandum 39-76, US Army Human Engineering Laboratory, *Helicopter Integrated Control (GAT-2H)*, December 1976.

2. Final Report, USAAEFA, Project No. 75-24, *Integrated Controller Evaluation*, September 1976.

3. Letter, AVSCOM, DRSAV-EQI, 26 April 1977, subject: MK II Integrated Controller Evaluation, USAAEFA Project No. 77-11.

4. Technical Manual, TM 55-1520-228-10, *Operator's Manual, Army Model OH-58A Helicopter*, September 1972, with Change 16.

5. Letter, AVRADCOM, DRDAV-EQI, 2 November 1977, subject: Airworthiness Release for USAAVRADCOM/USAAEFA Project No. 77-11.

6. Test Plan, USAAEFA, Project No. 77-11, *Flight Evaluation MK II Integrated Controller Installed in an OH-58A Helicopter*, July 1977.

7. Final Report, US Army Aviation Systems Test Activity (USAASTA), Project No. 68-30, *Airworthiness and Flight Characteristics Test, Production OH-58A Helicopter Unarmed and Armed with XM27E1 Armament Subsystem, Stability and Control*, October 1970.

8. Flight Test Manual, Naval Air Test Center, FTM No. 101, *Stability and Control*, 10 June 1968.

9. Final Report, USAASTA, Project No. 72-06, *Instrument Flight Evaluation. OH-6A Helicopter, Part I*, November 1973.

APPENDIX B. MK II INTEGRATED CONTROLLER DESCRIPTION REFERENCS

GENERAL

1. The MK II integrated controller combines conventional helicopter cyclic and collective controls into one control device capable of being operated by either hand. The integrated controller has approximately 66 percent lateral authority and 81 percent longitudinal authority of the conventional cyclic controls. A built-in safety feature is the ability of the safety pilot to decouple the integrated controller from the conventional control system. This is accomplished through the use of decoupler devices installed in the longitudinal, lateral, and collective control systems. The ability to decouple the integrated controller was verified prior to flight test.

2. The integrated controller consists of a vertical column which provides collective control (photo 1). Two opposing handgrips located near the top of the vertical column provide longitudinal and lateral control. The handgrips are interconnected and may be operated with one hand.

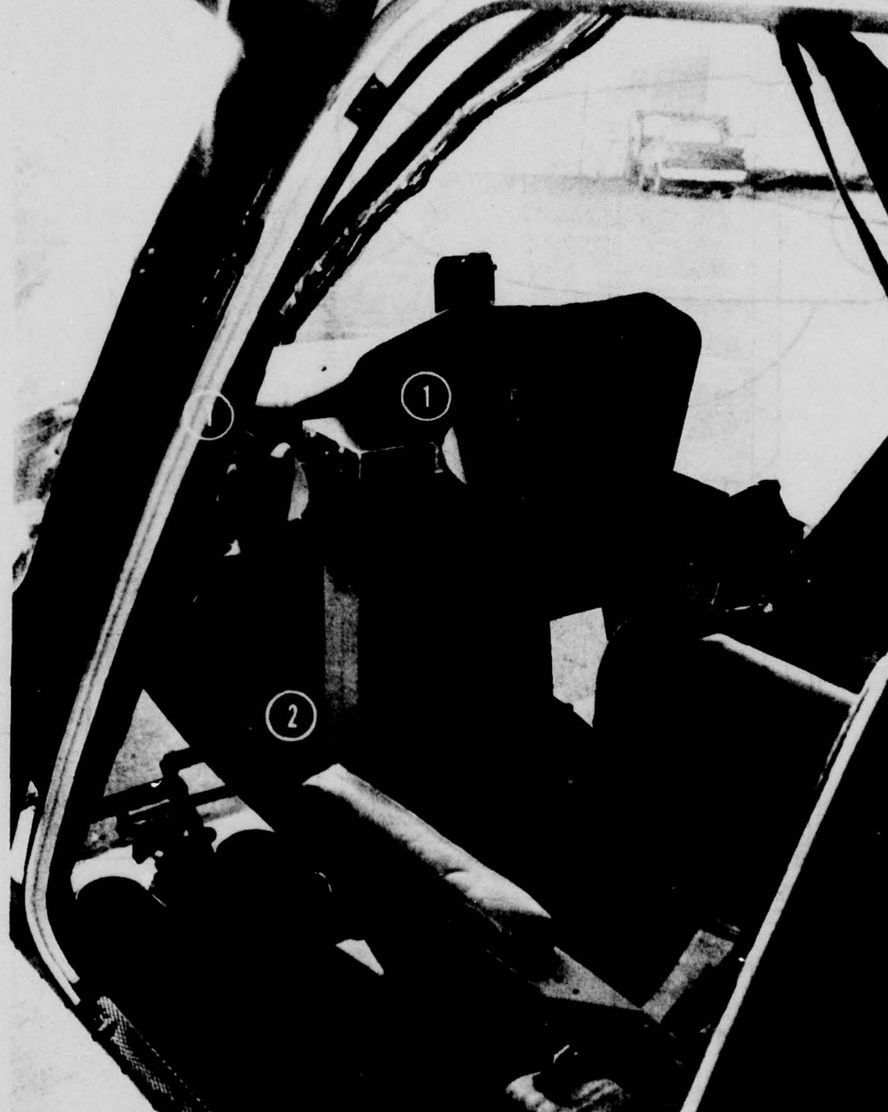
LONGITUDINAL

3. Longitudinal pitch control is achieved by rotation of the handgrips about a lateral axis extending through both grips. Rotation of the handgrip forward (top of grip away from pilot) produces a nose-down pitch movement of the aircraft. Similarly, a rotation rearward (top of grip toward pilot) produces a nose-up pitch movement of the aircraft. The control input is transferred to a push-pull rod (fig. 1), a bell crank, another push-pull rod (fig. 2), through a decoupler (fig. 3), to a wishbone connection (fig. 4), which joins the integrated longitudinal control to the conventional flight controls.

4. The integrated controller handgrips rotate 72 degrees in the longitudinal direction. This rotation moves the conventional cyclic 9.7 inches. Full longitudinal travel of the conventional cyclic is 12 inches. Thus, the integrated longitudinal control has 81 percent of full authority. This represents an increase in authority over the MK I system which was 68 percent.

LATERAL

5. Lateral control is achieved by rotating either handgrip about a longitudinal axis through its midpoint. Clockwise rotation (as seen by the pilot) of the grips produces a right roll movement of the aircraft. Counterclockwise rotation produces a left roll movement of the aircraft. Rotation of grips transfers an input to a



1. Cyclic control handgrips. 2. Collective control column.

Photo 1. Integrated Controller Installation.

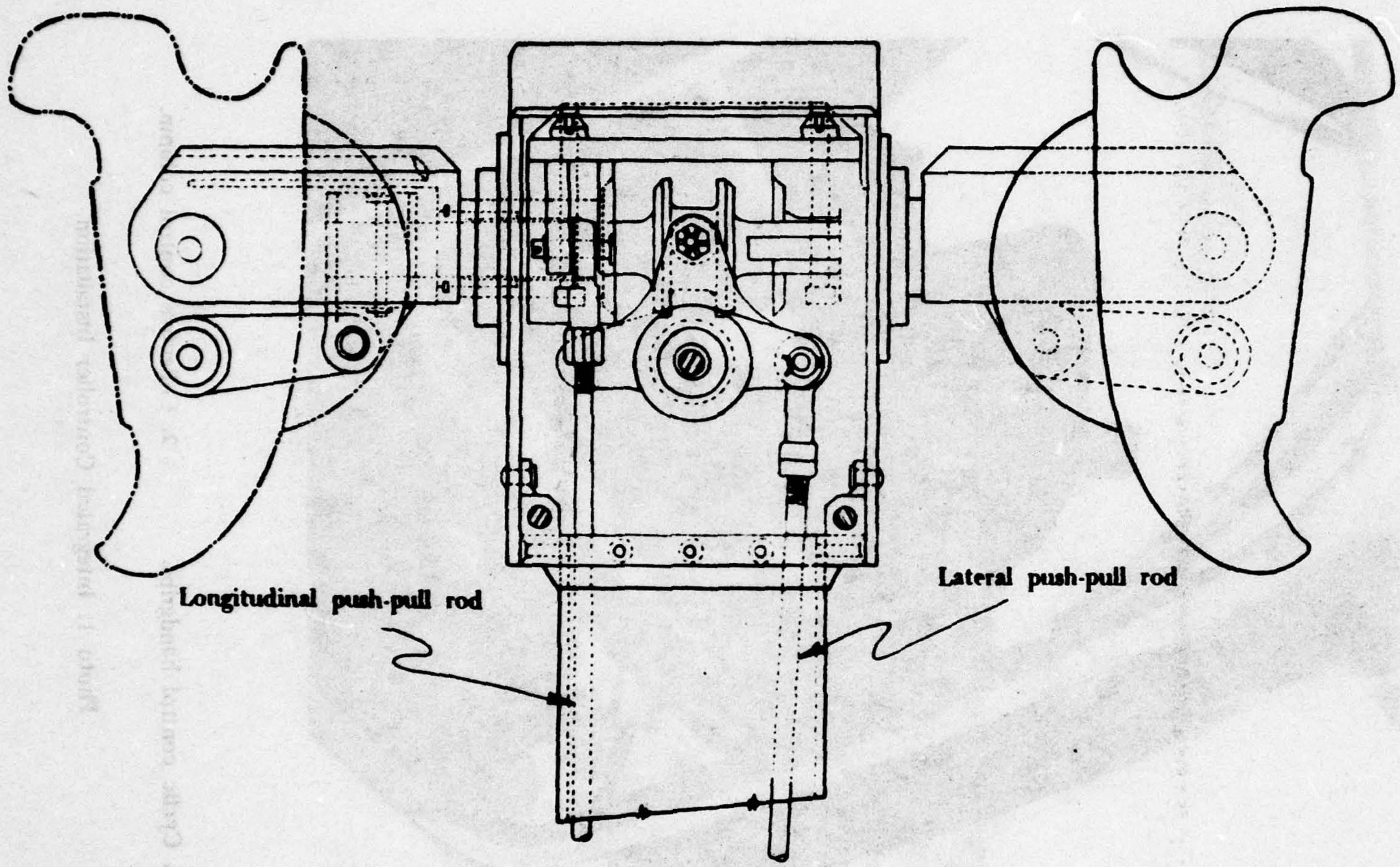


Figure 1. Integrated Controller Handgrips.

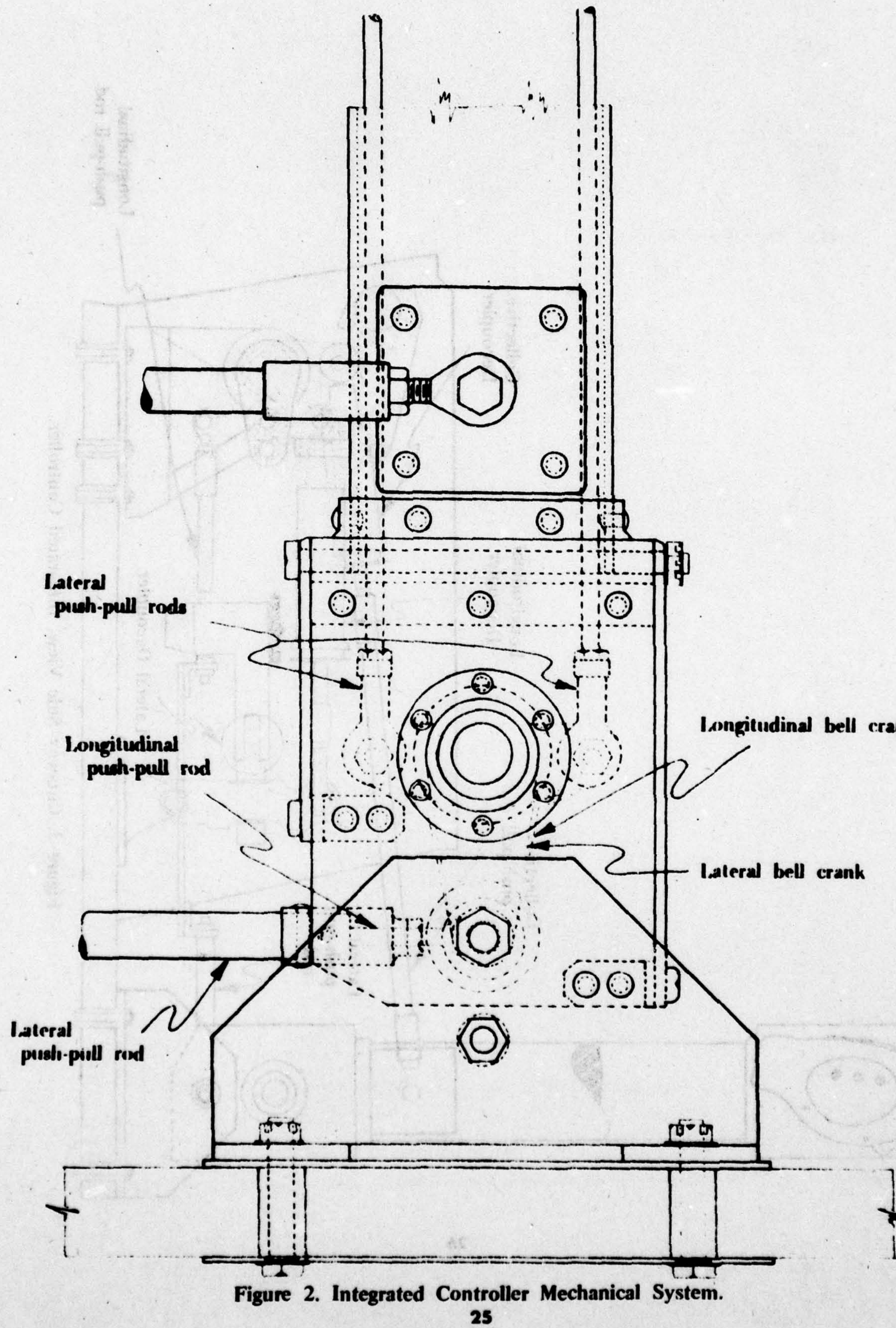


Figure 2. Integrated Controller Mechanical System.

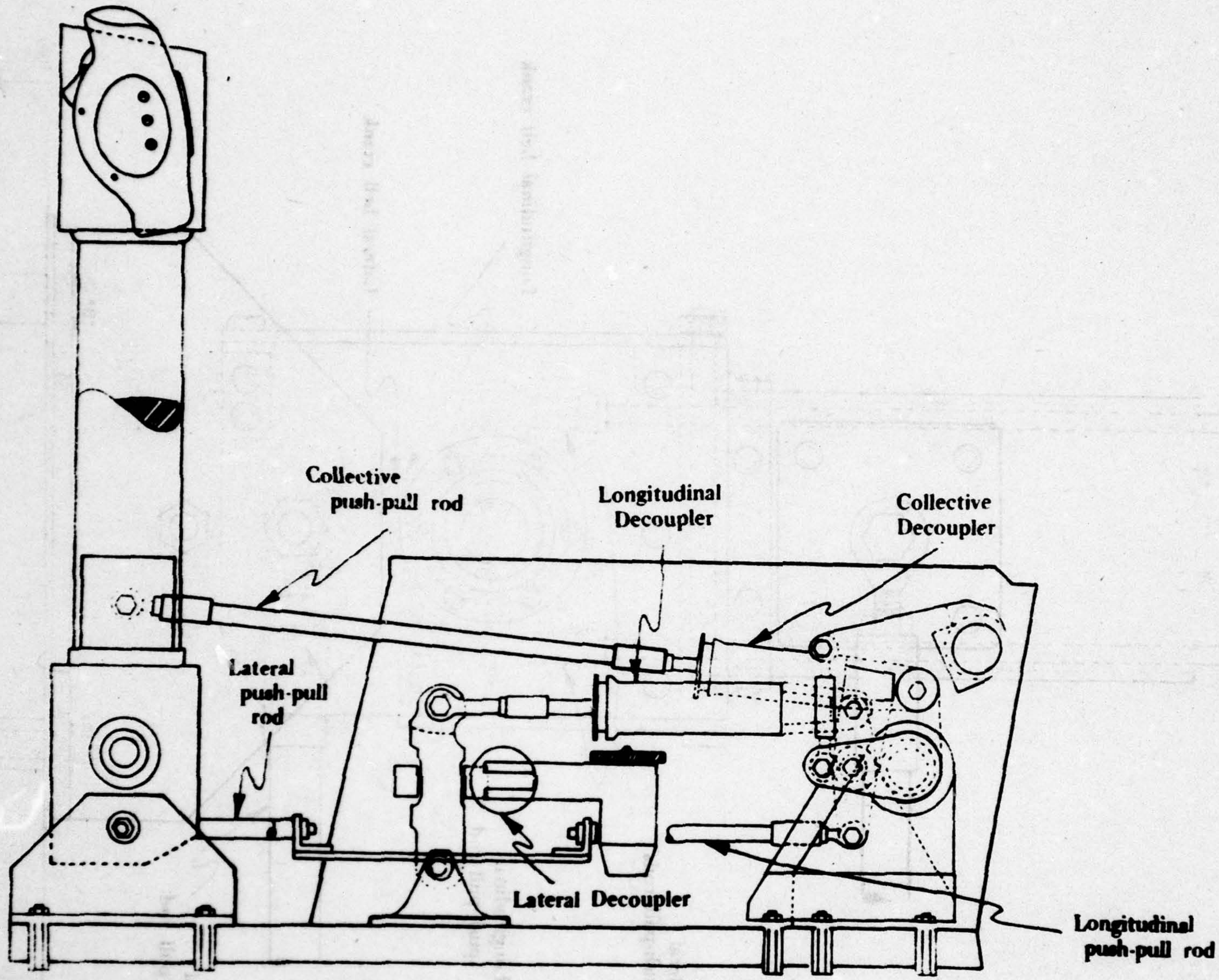


Figure 3. Cutaway Side View, Integrated Controller.

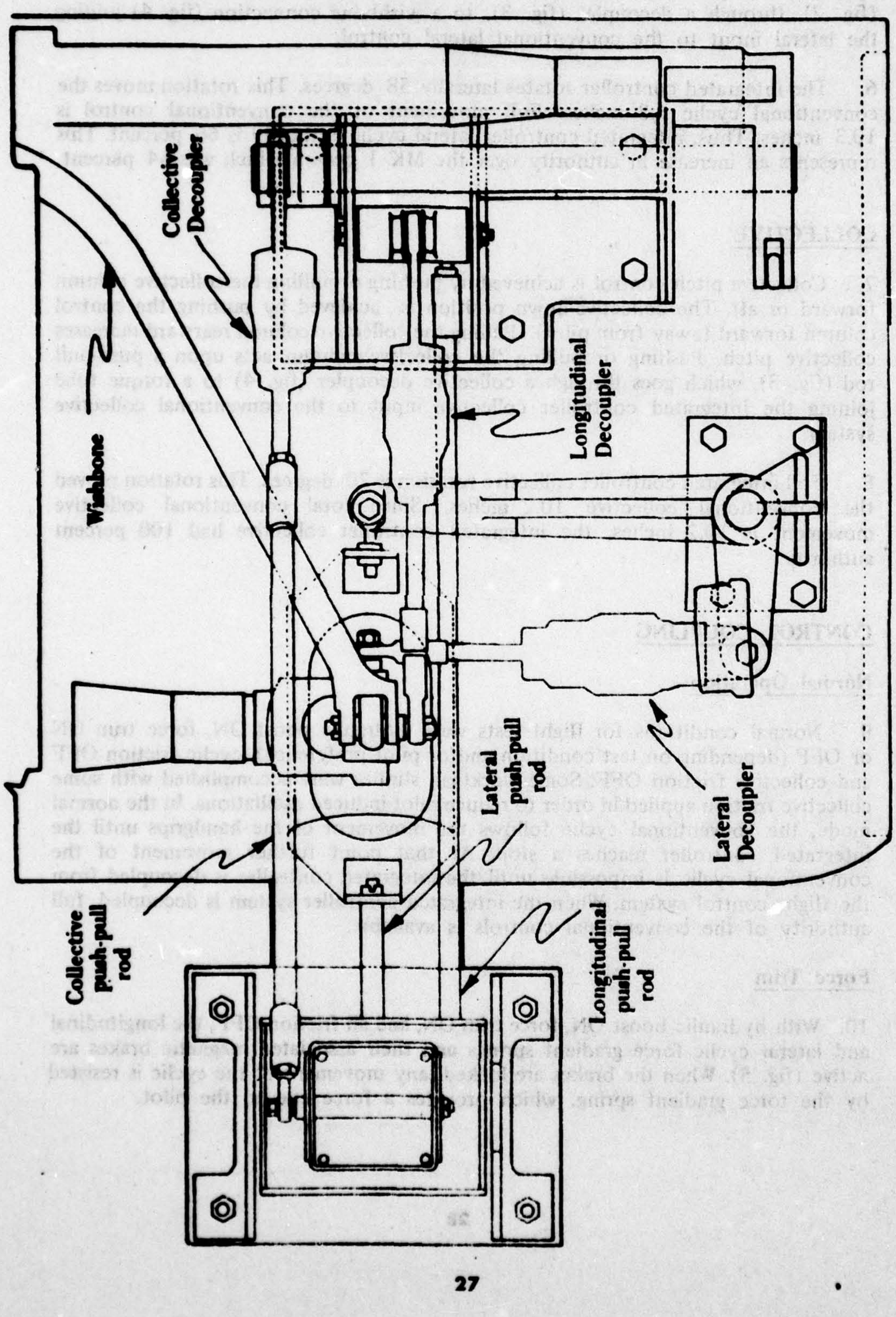


Figure 4. Integrated Controller Decouplers and Control Rods.

bell crank, a push-pull rod (fig. 1), a second bell crank and push-pull system (fig. 2), through a decoupler (fig. 3), to a wishbone connection (fig. 4) joining the lateral input to the conventional lateral control.

6. The integrated controller rotates laterally 58 degrees. This rotation moves the conventional cyclic 6.8 inches. Full movement of the conventional control is 10.3 inches. Thus, integrated controller lateral cyclic authority is 66 percent. This represents an increase in authority over the MK I system which was 64 percent.

COLLECTIVE

7. Collective pitch control is achieved by pushing or pulling the collective column forward or aft. The collective-down position is achieved by pushing the control column forward (away from pilot). Pulling the collective column rearward increases collective pitch. Pushing or pulling the collective column acts upon a push-pull rod (fig. 3), which goes through a collective decoupler (fig. 4) to a torque tube joining the integrated controller collective input to the conventional collective system.

8. Full integrated controller collective rotation is 20 degrees. This rotation moved the conventional collective 10.2 inches. Since total conventional collective movement is 10.2 inches, the integrated controller collective had 100 percent authority.

CONTROL COUPLING

Normal Operation

9. Normal conditions for flight tests were hydraulic boost ON, force trim ON or OFF (depending on test condition and/or pilot preference), cyclic friction OFF and collective friction OFF. Some workload studies were accomplished with some collective friction applied in order to reduce pilot-induced oscillations. In the normal mode, the conventional cyclic follows the movement of the handgrips until the integrated controller reaches a stop. At that point further movement of the conventional cyclic is impossible until the integrated controller is decoupled from the flight control system. When the integrated controller system is decoupled, full authority of the conventional controls is available.

Force Trim

10. With hydraulic boost ON, force trim ON, and all friction OFF, the longitudinal and lateral cyclic force gradient springs and their associated magnetic brakes are active (fig. 5). When the brakes are locked, any movement of the cyclic is resisted by the force gradient spring, which provides a force cue to the pilot.

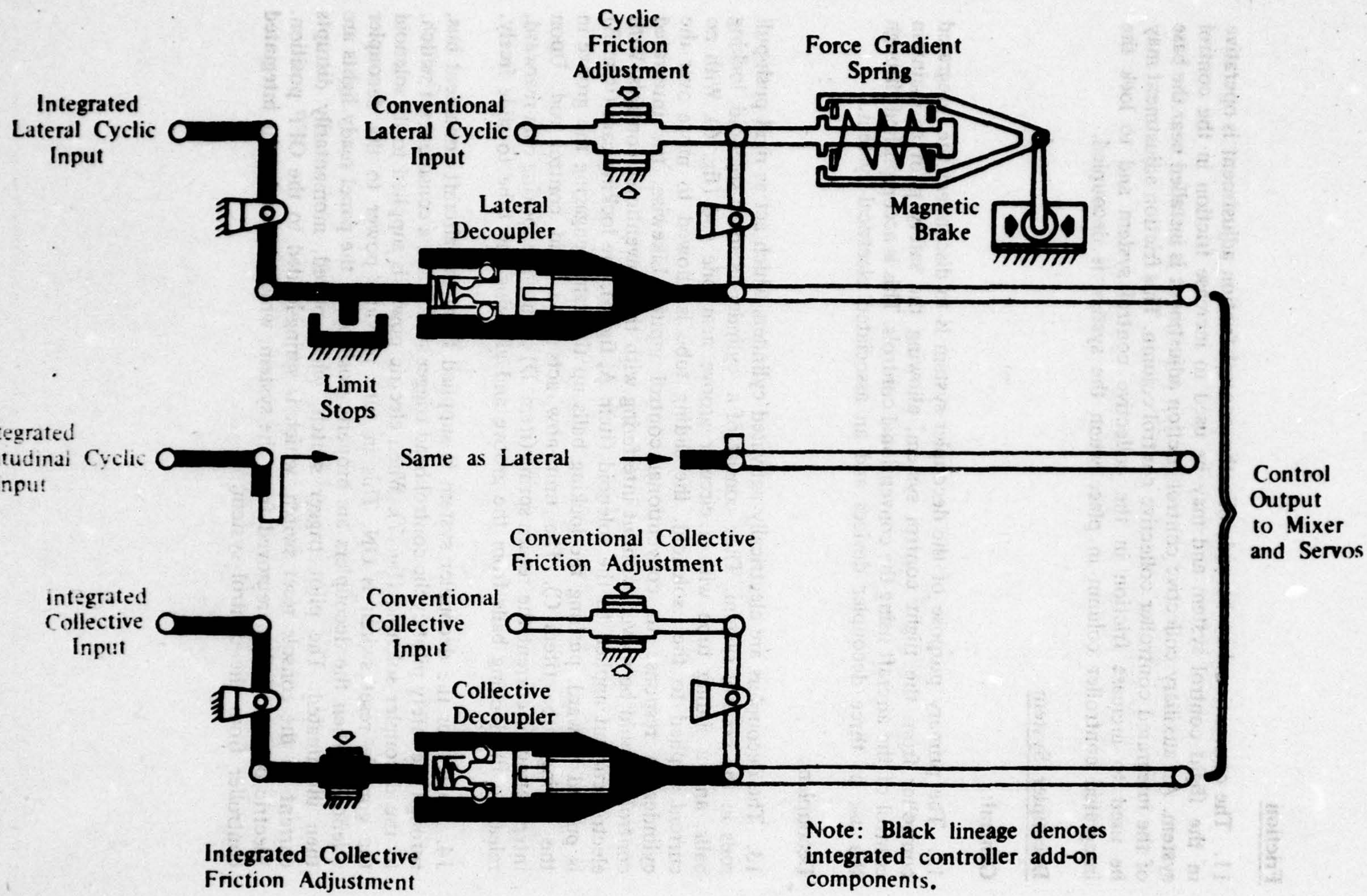


Figure 5. Integrated Controller Coupling Schematic.

Friction

11. The conventional cyclic and collective control friction adjustment is operative in the flight control system and may be used to increase friction in the control system. An auxiliary collective control friction adjustment is installed near the base of the integrated controller collective control column. This friction adjustment may be used to increase friction in the collective control system and to lock the integrated controller column in place when the system is decoupled.

Decoupler System

General:

12. The primary purpose of the decoupler system is to disconnect the integrated controller from the flight control system, allowing the safety pilot to maintain control of the aircraft using the conventional controls. This is accomplished through the use of three decoupler devices and an associated electrical system.

Decouplers:

13. The decouplers are electrically activated cylinders which act as rigid push-pull rods in the control system. They consist of a cylinder-enclosed solenoid, locking balls, and a sliding tube with a circular groove near one end (fig. 6). With no current applied to the solenoid, the sliding tube is allowed to move over the cylinder in response to conventional control inputs. Likewise, the integrated controller could be moved without interfering with the conventional controls. With electric current applied to the solenoid (item A, fig. 6), the locking cam (item B) is pushed forward, pushing the locking balls up the ramp engaging the groove in the sliding tube (item C). The unit now acts as a rigid control rod. Upon interruption of current the return spring (item D) pushes the locking cam rearward, releasing the locking balls from the groove and allowing the tube to slide freely.

14. Power for the decoupler system is supplied from the aircraft armament bus, through the safety pilot cyclic control head trigger switch and a console reset switch, to the decoupler solenoid (fig. 7). When electric power is supplied to its solenoid the console reset switch is ON. This in turn provides power to the decoupler solenoids. When the decouplers are properly positioned, the panel ready lights are then illuminated. The pilot trigger switch, when pulled, momentarily disrupts current to the console reset switch, which is spring-loaded to the OFF position. Electric current is then removed from the system, which decouples the integrated controller from the control system.

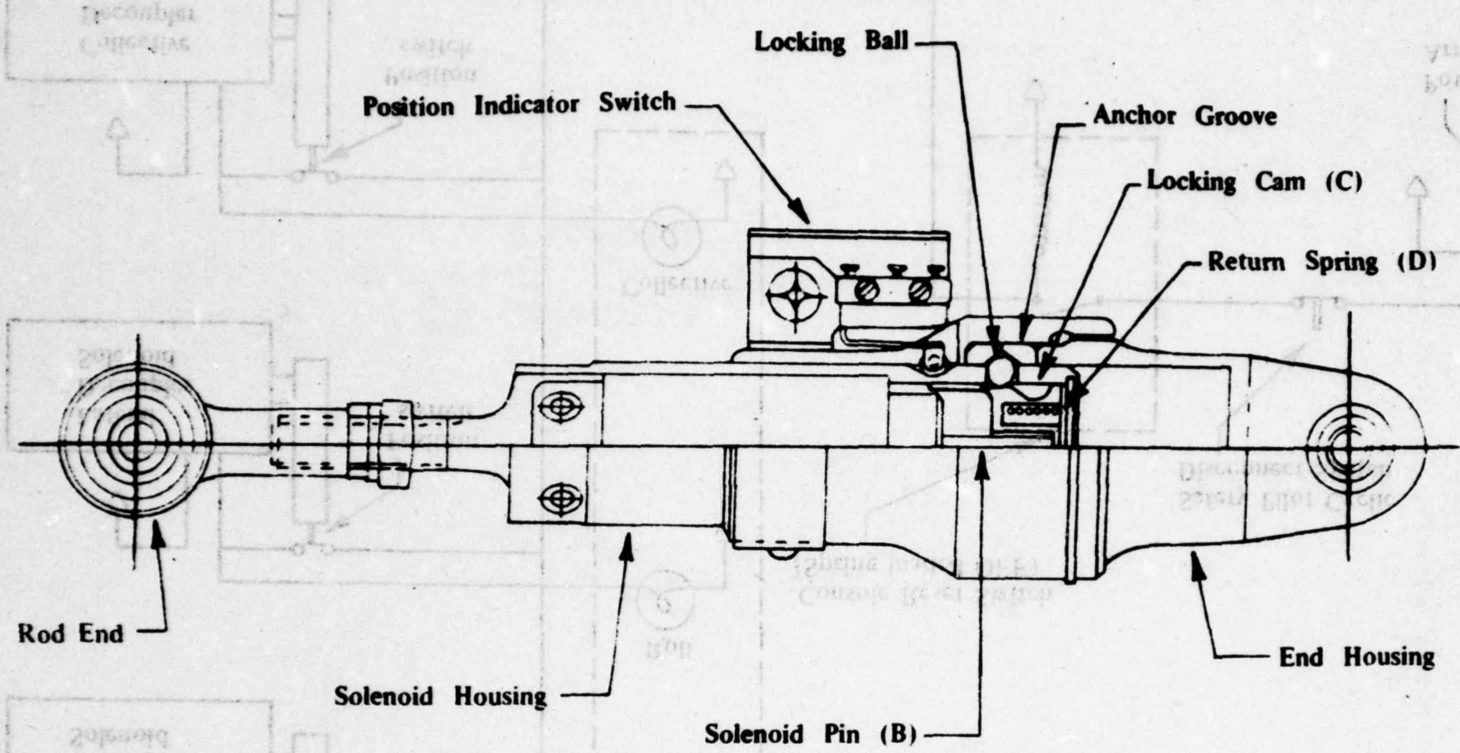


Figure 6. Decoupler Unit.

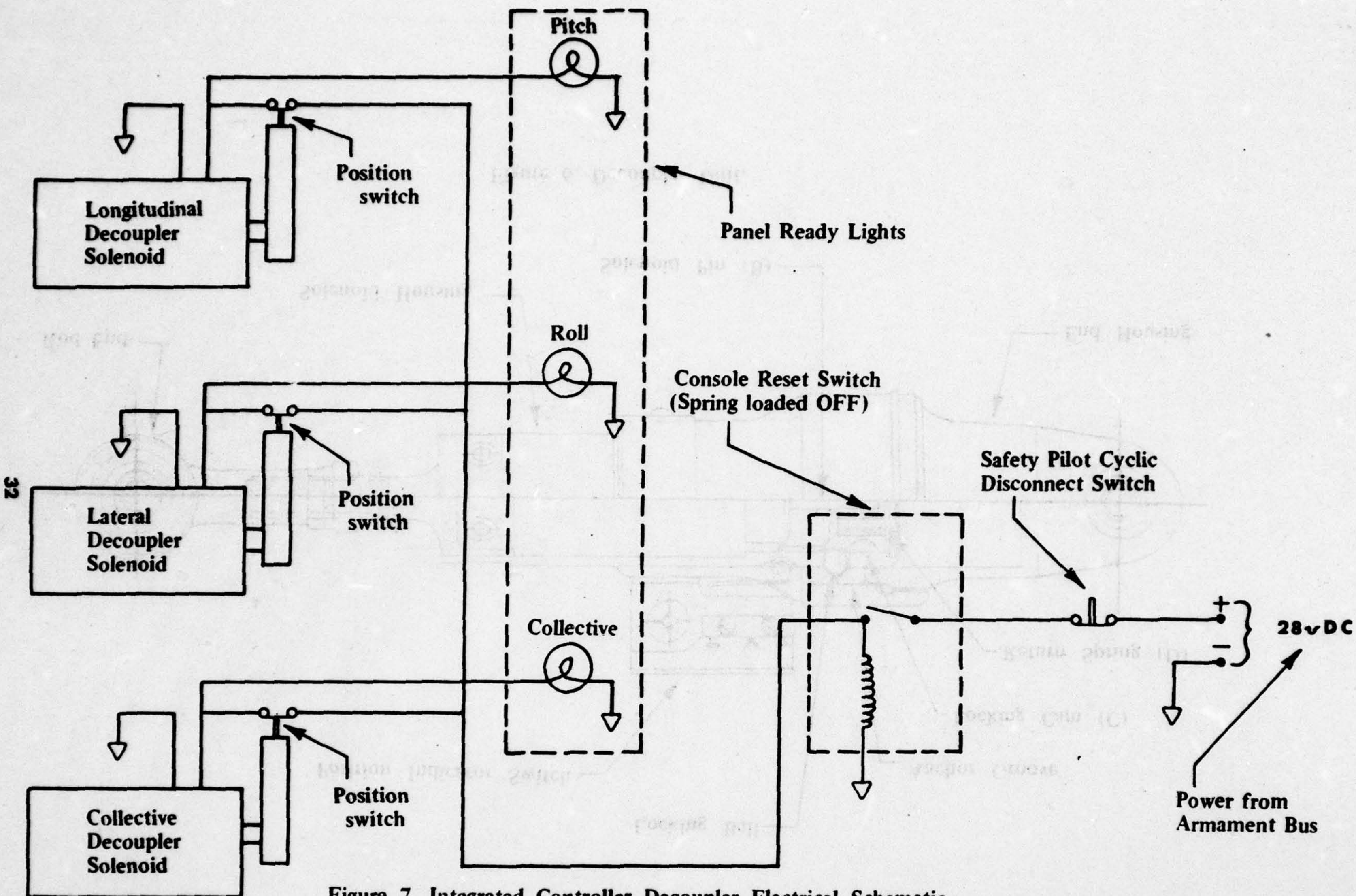


Figure 7. Integrated Controller Decoupler Electrical Schematic.

APPENDIX C. INSTRUMENTATION

1. The test instrumentation system was designed, installed, calibrated, and maintained by USAAEFA. Test data were hand-recorded from cockpit instruments and were recorded by an on-board magnetic tape recording system.

2. The following parameters were recorded from test instrumentation installed in the cockpit:

Airspeed (ship's system)
Altitude (ship's system)
Event mark
Time code

3. The following parameters were recorded from standard aircraft instruments in the cockpit:

Outside air temperature
Rotor speed
Engine torque
Turbine outlet temperature
Gas producer speed
Attitude

4. The following parameters were recorded on the magnetic tape recording system. Selected parameters were telemetered to a ground station for real time monitoring.

Time code
Event marker
Airspeed (ship's system)
Altitude (ship's system)
Control positions:
- Longitudinal
- Lateral
- Directional
- Collective

Attitudes and angular rates:
- Pitch
- Roll
- Yaw

Accelerations:
- Cg normal
- Cg lateral
- Cg longitudinal

APPENDIX D. TEST TECHNIQUES AND DATA ANALYSIS METHODS

HANDLING QUALITIES

1. Handling qualities data were collected and evaluated using standard test methods as described in reference 8, appendix A. The Handling Qualities Rating Scale presented in figure 1 was used to augment pilot comments relative to handling qualities and workload. Definitions of deficiencies and shortcomings are as stipulated in Army Regulation 310-25.

PILOT WORKLOAD EVALUATION

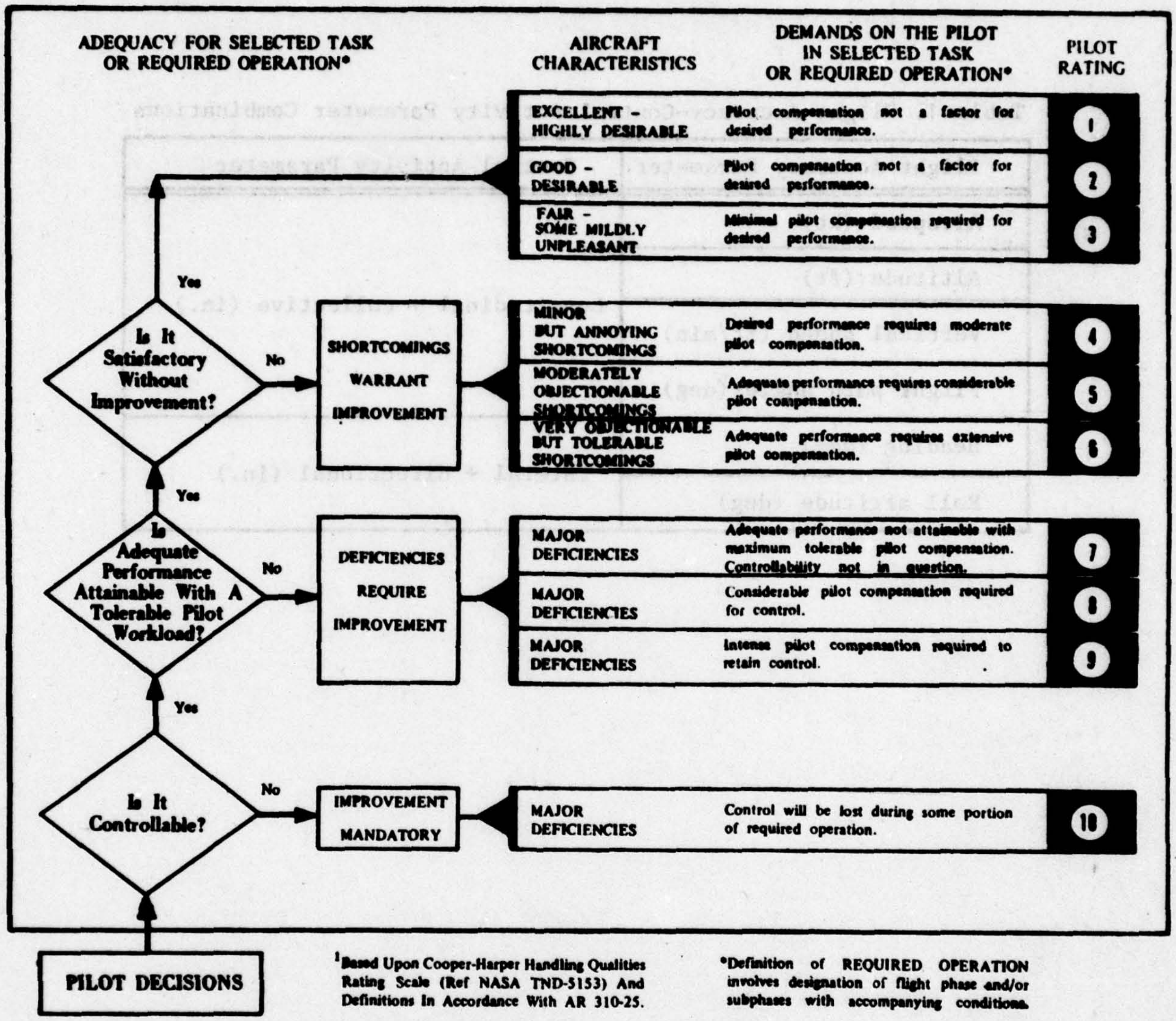
2. Flight data for the workload evaluation were recorded on magnetic tape at a rate of 20 samples per second. Control position data for the integrated controller were recorded in degrees of control rotation and were converted to inches of movement of the conventional controls for comparison with the conventional controls and for use in the quantitative analyses. All test runs were of 1-minute duration. Each test maneuver was flown using conventional controls to establish a base line and later repeated using the integrated controller. For further comparison, another pilot also completed the same test sequence.

3. In an attempt to quantify workload and achieve correlation with qualitative pilot ratings, several analysis techniques were employed. The first involved the use of a flight accuracy-control activity analysis computer program. This computer program performs analyses on time history recordings of flight parameters and aircraft control data. A description of the program and its operation is contained in reference 9, appendix A. Previous experience has shown that flight accuracy and control activity data cannot be analyzed separately; therefore, the control axes were combined and related to flight accuracy parameters as shown in table 1.

4. A flight accuracy-control activity factor was then calculated by multiplying the flight accuracy parameter by the corresponding control activity parameter. The factor gives an indication of flight accuracy and control activity combined, to be used for comparative evaluations of specific flight maneuvers.

5. The second method employed involved analyzing the amplitude and number of control reversals per unit time. Statistical data were computed for each control axis of both control types during various flight maneuvers. The number of times a control was reversed in a given deflection band or zone per unit of time was considered a measure of pilot workload. Each zone was defined as being 1 percent of the full travel of the control.

6. The third method involved a variance analysis of each control axis for both control types. The statistical test involved a null hypothesis, which was tested,



[1]Based Upon Cooper-Harper Handling Qualities Rating Scale (Ref NASA TND-5153) And Definitions In Accordance With AR 310-25.

*Definition of REQUIRED OPERATION involves designation of flight phase and/or subphases with accompanying conditions.

Figure 1. Handling Qualities Rating Scale.

Table 1. Flight Accuracy-Control Activity Parameter Combinations

Flight Accuracy Parameter	Control Activity Parameter
Airspeed (kt)	Longitudinal + collective (in.)
Altitude (ft)	
Vertical speed (ft/min)	
Flight path angle (deg)	
Heading (deg)	Lateral + directional (in.)
Roll attitude (deg)	

and an alternative hypothesis. For this analysis the null hypothesis was: the integrated controller workload is the same as conventional control workload during a particular maneuver. The alternate hypothesis was: the integrated controller workload is greater than conventional control workload during a particular maneuver. Rejecting the null hypothesis is often considered statistically equivalent to accepting the alternate hypothesis. The variance of the conventional control positions was determined for each control axis during each maneuver. This variance was compared to the variance of the integrated controller positions for the same maneuver. If the workload is the same, then the ratio of their variances (F value) should be nearly equal to 1. By comparing this F value to a table of F values for the sample size, it can be determined whether the null hypothesis is valid.

APPENDIX E. TEST DATA

INDEX

FIGURE 1
LONGITUDINAL AND LATERAL INTEGRATED CONTROL PATTERN
OH-58A USA S/N 71-20380

NOTES:
1. GROUND STATIC
2. HYDRAULIC AND ELECTRICAL POWER PROVIDED BY GROUND POWER UNITS
3. COLLECTIVE CONTROL FULL FORWARD (CONVENTIONAL FULL DOWN)
4. NO LONGITUDINAL AND LATERAL CONTROL PATTERN CHANGE WITH CHANGE OF COLLECTIVE CONTROL POSITION

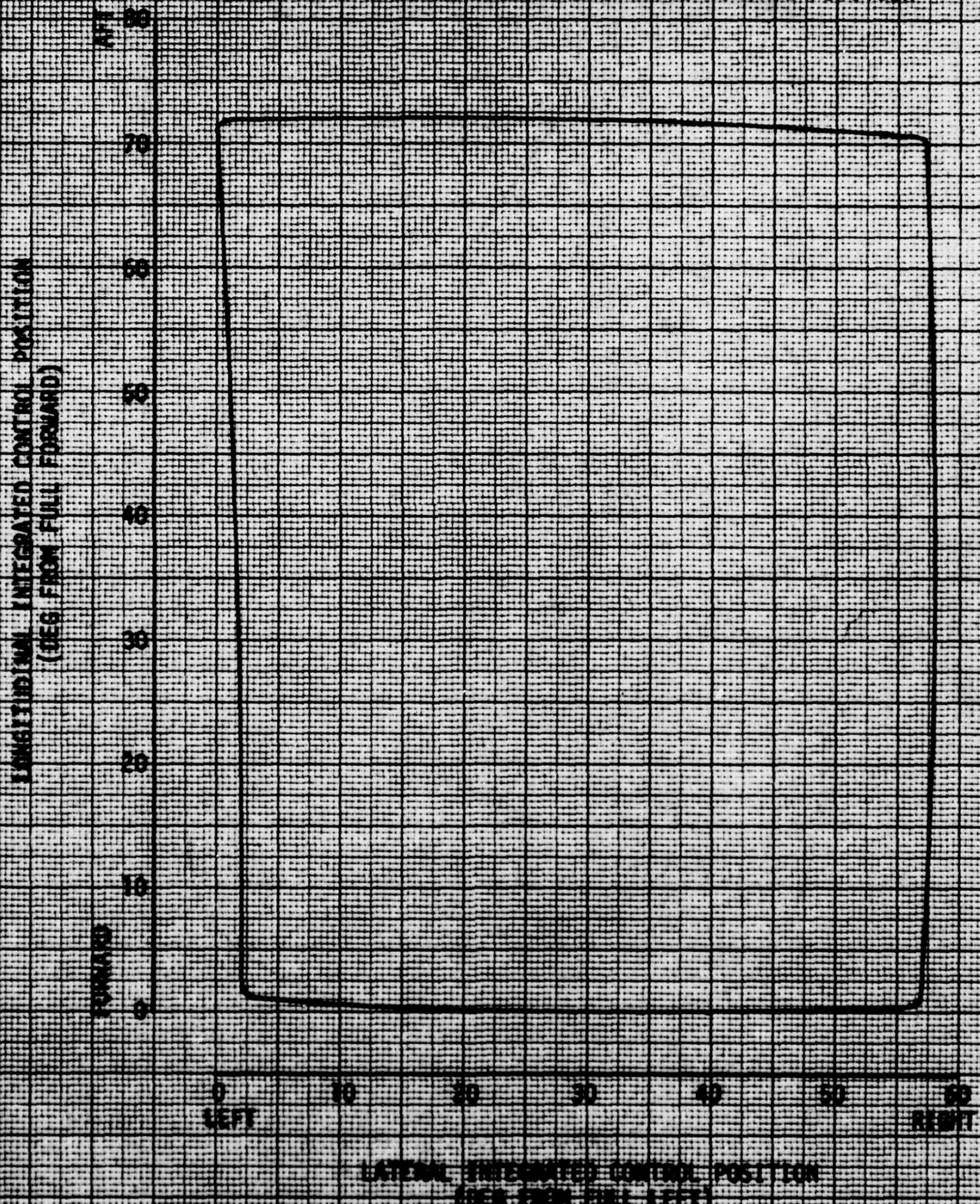


FIGURE 2
INTEGRATED CONTROLLER AUTHORITY
JUH-60A USA S/N 77-22[illegible]

NOTE: INTEGRATED CONTROLLER PATTERN OBTAINED BY CONVERTING ANGULAR DISPLACEMENT IN FIG. 1 TO EQUIVALENT INCHES OF CONVENTIONAL CYCLIC.

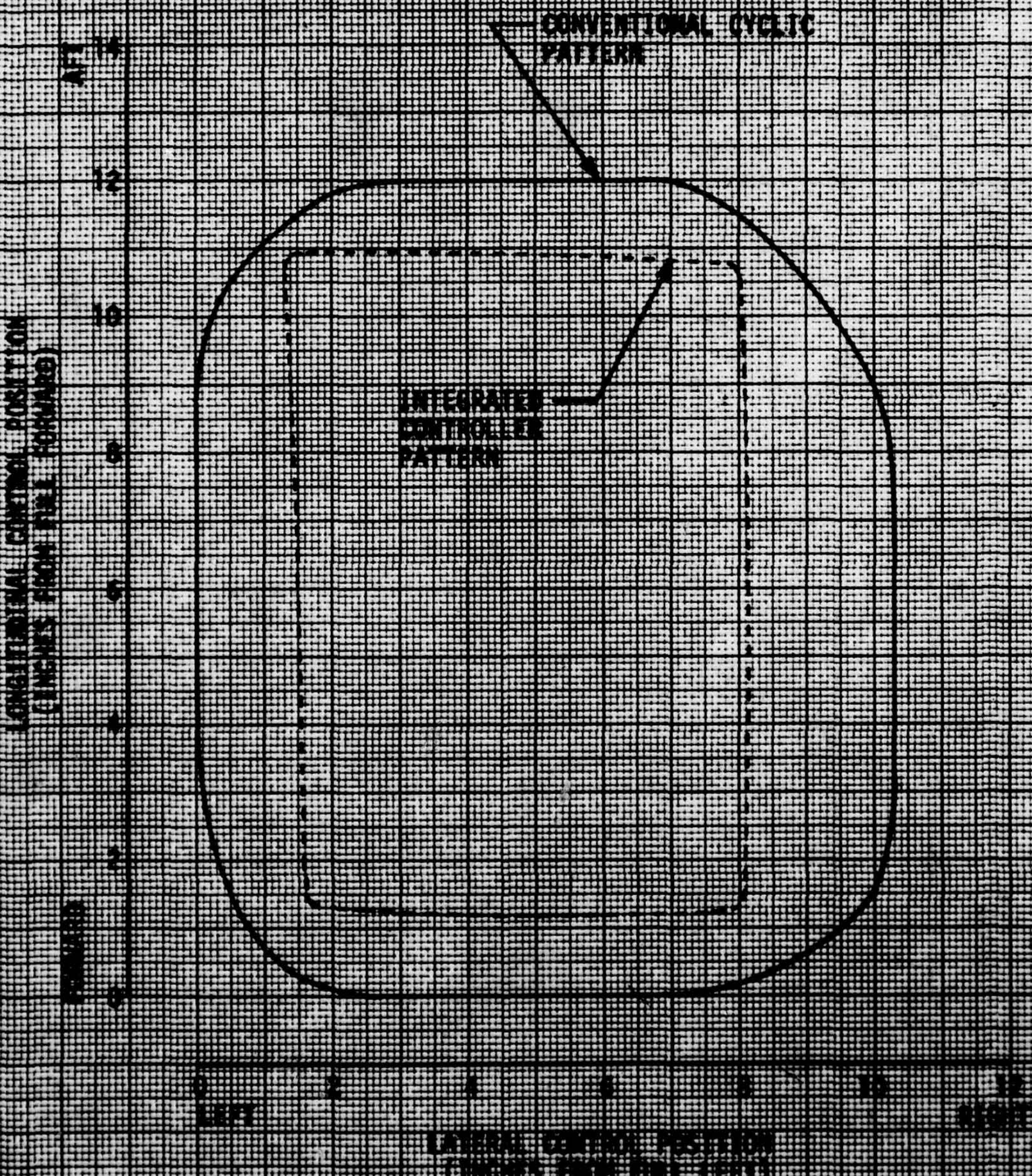


FIGURE 3
LONGITUDINAL INTEGRATED CONTROL SYSTEM CHARACTERISTICS
JOH-58A USA S/N 71-20380

NOTES: 1. ROTORS STATIC
2. HYDRAULIC AND ELECTRICAL POWER PROVIDED BY GROUND POWER UNITS
3. TOTAL LONGITUDINAL CONTROL TRAVEL = 72 DEGREES
4. LATERAL CONTROL POSITION = 30 DEGREES FROM FULL LEFT
5. FORCE TRIM ON, CYCLIC FRICTION AT ZERO
6. COLLECTIVE CONTROL FULL FORWARD (CONVENTIONAL FULL DOWN)

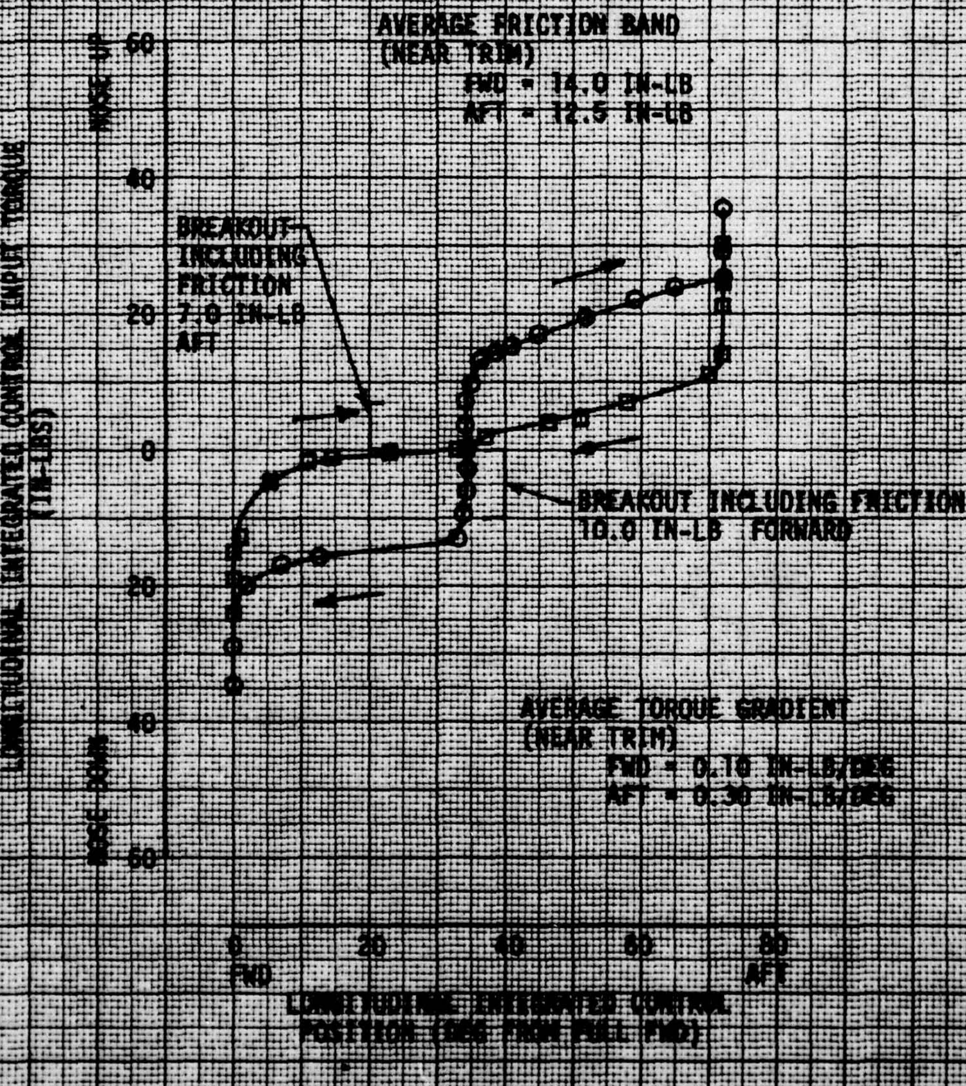
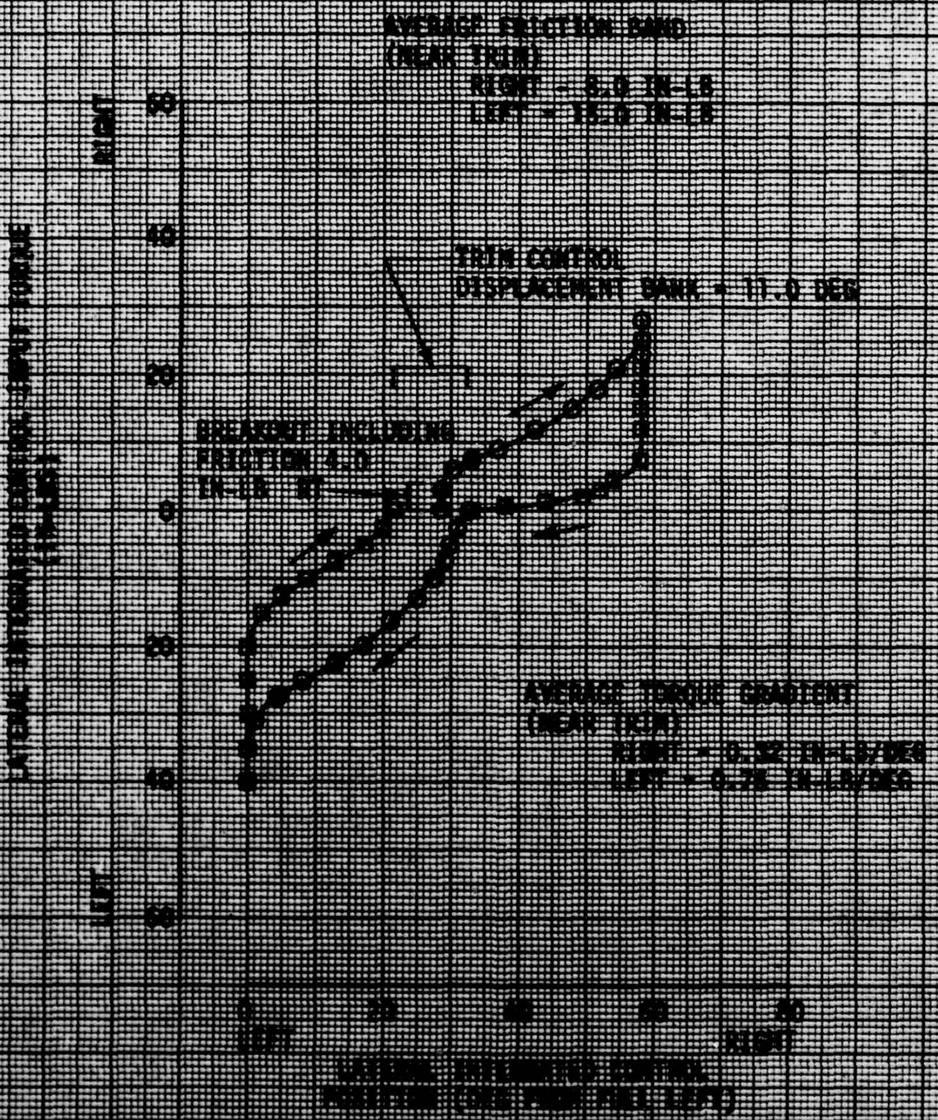


FIGURE 6
LATERAL INTEGRATED CONTROL SYSTEM CHARACTERISTICS
[illegible]

NOTES:
1. ROTORS STATIC.
2. HYDRAULIC AND ELECTRICAL POWER PROVIDED BY GROUND POWER UNITS.
3. TOTAL LATERAL CONTROL TRAVEL = 58 DEGREES.
4. LONGITUDINAL CONTROL POSITION = 50 DEGREES FROM FULL FORWARD.
5. FORCE TRIM ON, CYCLIC FRICTION AT ZERO.
6. COLLECTIVE CONTROL FULL FORWARD (CONVENTIONAL FULL DOWN).



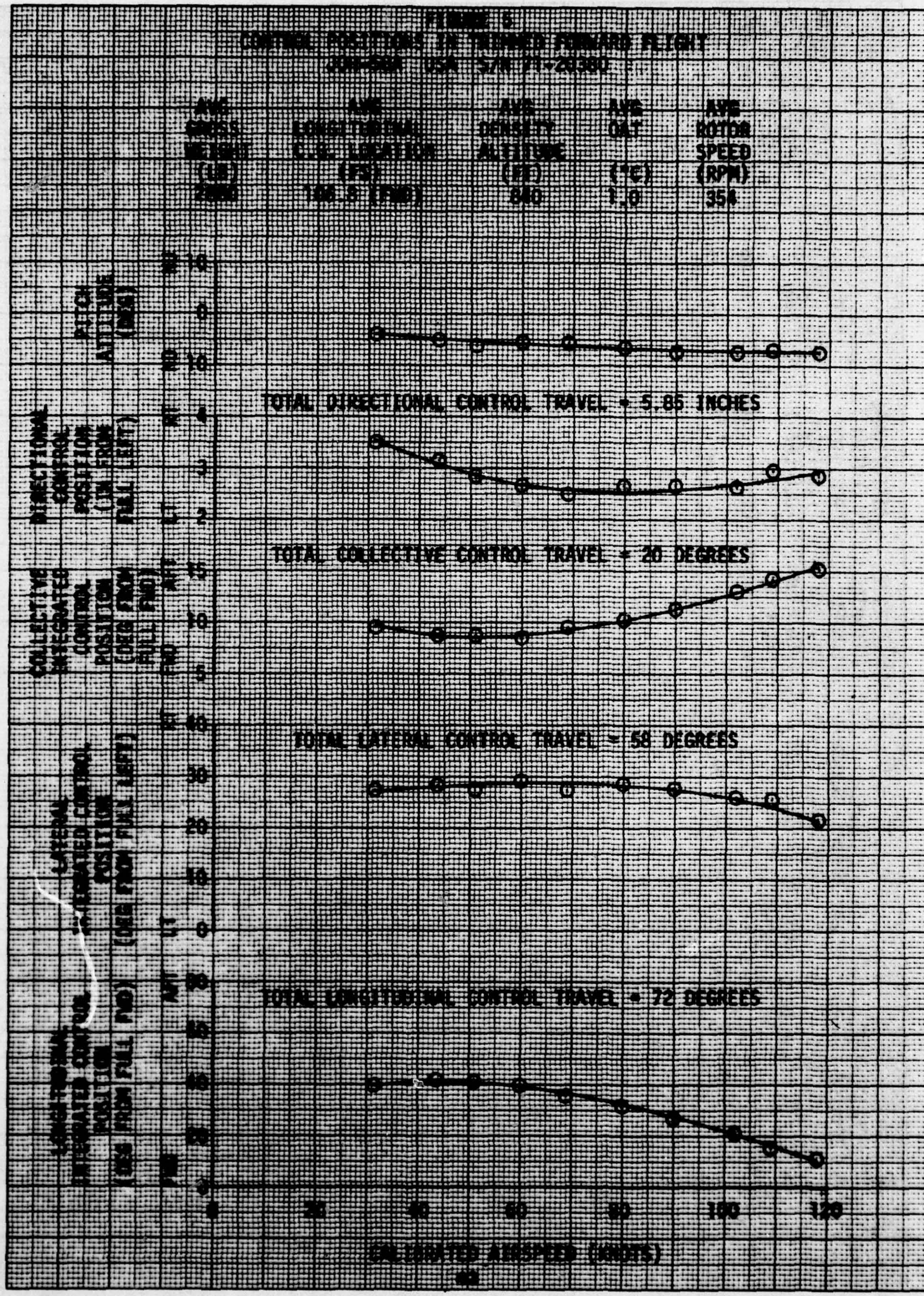
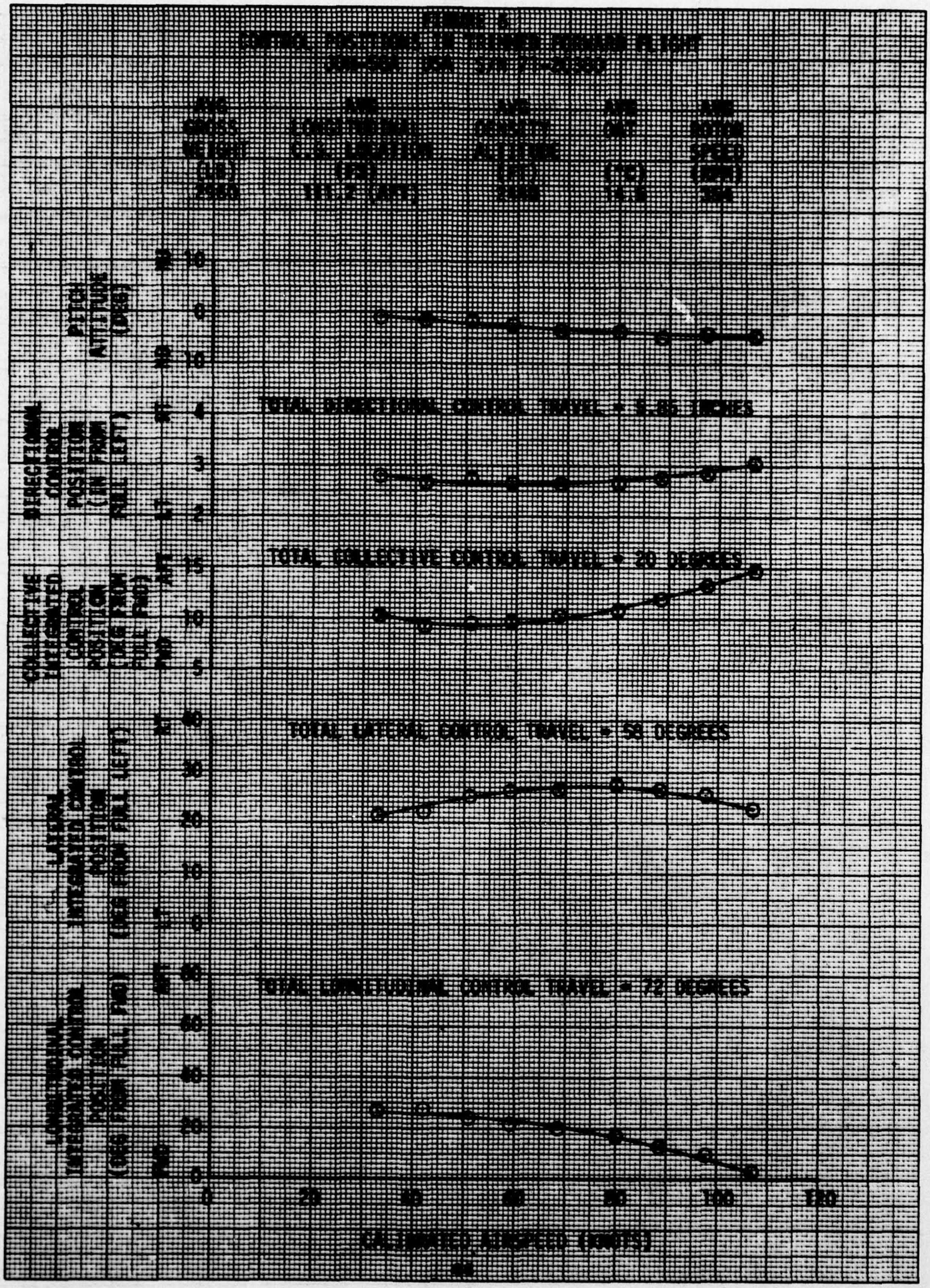


FIGURE 5
CONTROL POSITIONS IN TRIMMED FORWARD FLIGHT
JOH-58A USA S/N 71-20380
AVG GROSS WEIGHT (LB) 2800
AVG LONGITUDINAL C.G. LOCATION (FS) 106.5 (FWD)
AVG DENSITY ALTITUDE (FT) 840
AVG OAT (°C) 1.0
AVG ROTOR SPEED (RPM) 354
PITCH ATTITUDE (DEG)
ND
UP
10
0
10
DIRECTIONAL CONTROL POSITION (IN FROM FULL LEFT)
RT
LT
4
3
2
TOTAL DIRECTIONAL CONTROL TRAVEL = 5.85 INCHES
COLLECTIVE INTEGRATED CONTROL POSITION (DEG FROM FULL FWD)
AFT
FWD
15
10
5
TOTAL COLLECTIVE CONTROL TRAVEL = 20 DEGREES
LATERAL INTEGRATED CONTROL POSITION (DEG FROM FULL LEFT)
RT
LT
40
30
20
10
0
TOTAL LATERAL CONTROL TRAVEL = 58 DEGREES
LONGITUDINAL INTEGRATED CONTROL POSITION (DEG FROM FULL FWD)
AFT
FWD
TOTAL LONGITUDINAL CONTROL TRAVEL = 72 DEGREES
0
20
40
60
80
100
120
CALIBRATED AIRSPEED (KNOTS)



TOTAL DIRECTIONAL CONTROL TRAVEL = 5.85 INCHES
TOTAL COLLECTIVE CONTROL TRAVEL = 20 DEGREES
TOTAL LATERAL CONTROL TRAVEL = 58 DEGREES
TOTAL LONGITUDINAL CONTROL TRAVEL = 72 DEGREES
PITCH ATTITUDE (DEG)
DIRECTIONAL CONTROL POSITION (IN FROM FULL LEFT)
COLLECTIVE INTEGRATED CONTROL POSITION (DEG FROM FULL PWD)
LATERAL INTEGRATED CONTROL POSITION (DEG FROM FULL LEFT)
LONGITUDINAL INTEGRATED CONTROL POSITION (DEG FROM FULL FWD)
CALIBRATED AIRSPEED (KNOTS)

FIGURE 7
MANEUVERING STABILITY
OH-58A USA S/N 71-20389

AVG GROSS WEIGHT (LB)	AVG LONGITUDINAL C.G. LOCATION (FS)	AVG DENSITY ALTITUDE (FT)	AVG OAT (°C)	AVG ROTOR SPEED (RPM)	TRIM CALIBRATED AIRSPEED (KTS)
2820	106.3 (FWD)	1080	0.5	354	103

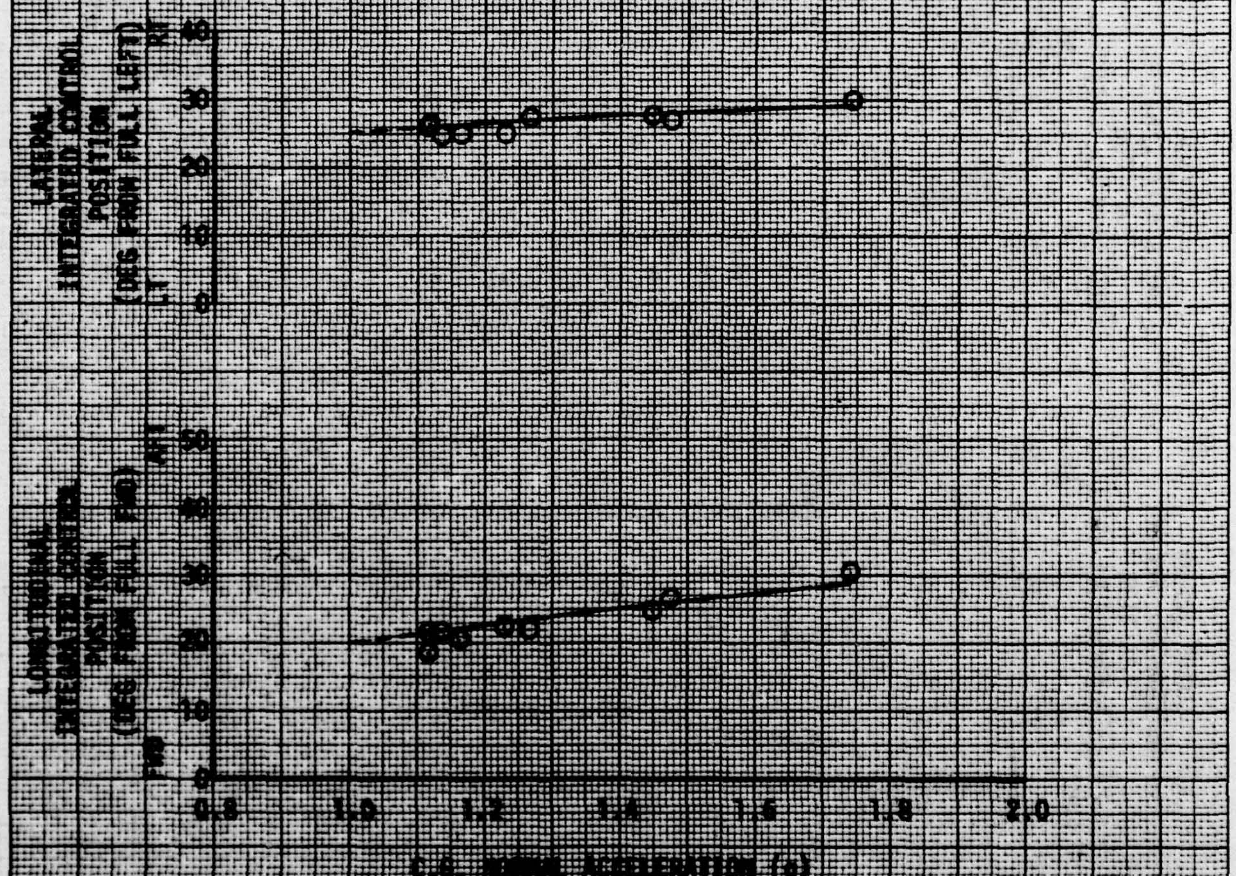


FIGURE 8
MANEUVERING STABILITY
OH-58A USA S/N 71-20360

SYM	AVG GROSS WEIGHT (LB)	AVG LONGITUDINAL C.G. LOCATION (FS)	AVG DENSITY ALTITUDE (FT)	AVG OAT (°C)	AVG ROTOR SPEED (RPM)	TRIM CALIBRATED AIRSPEED (KTS)
△	2880	111.0 (AFT)	2220	14.0	354	62
○	2920	111.1 (AFT)	2500	15.0	354	102

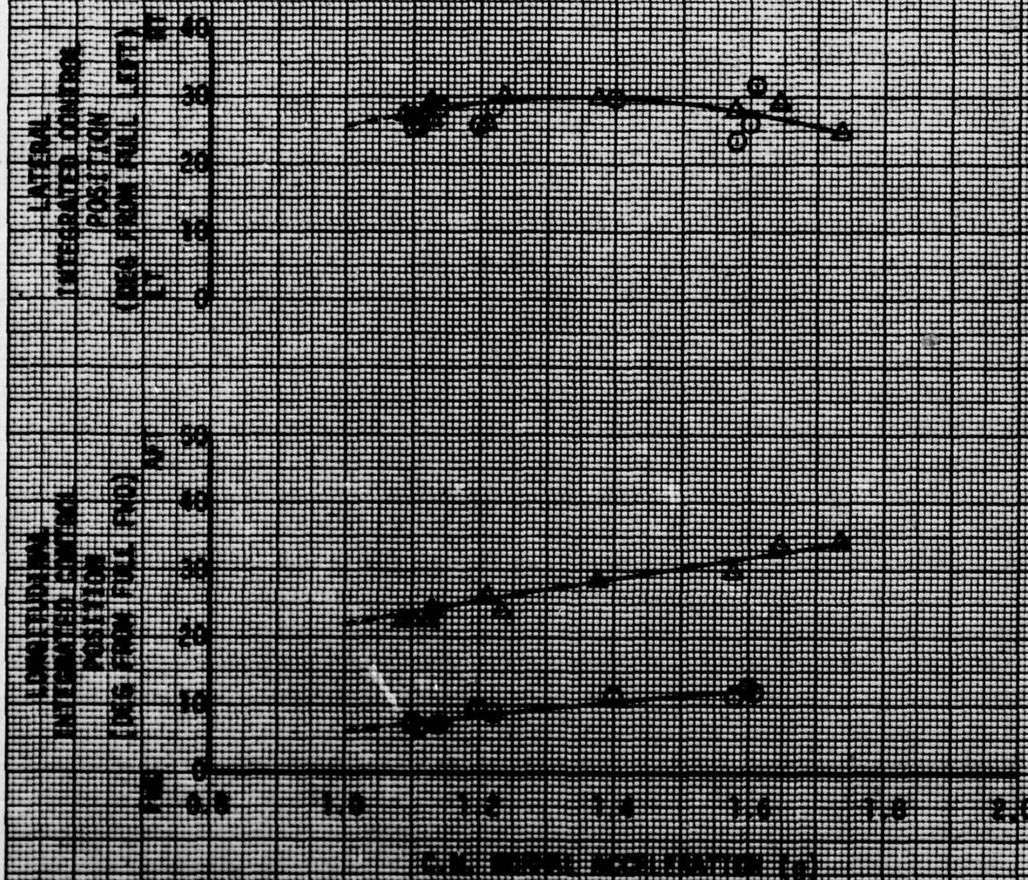
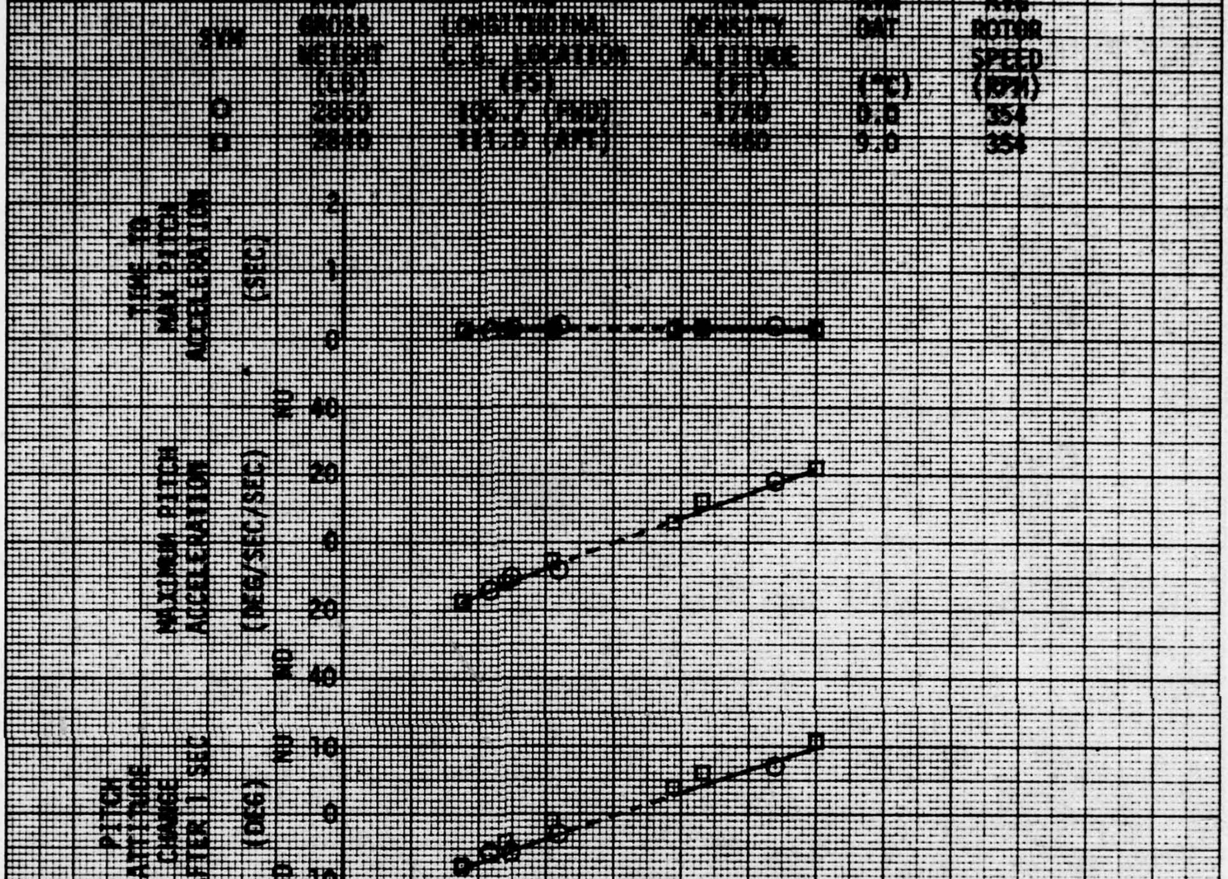
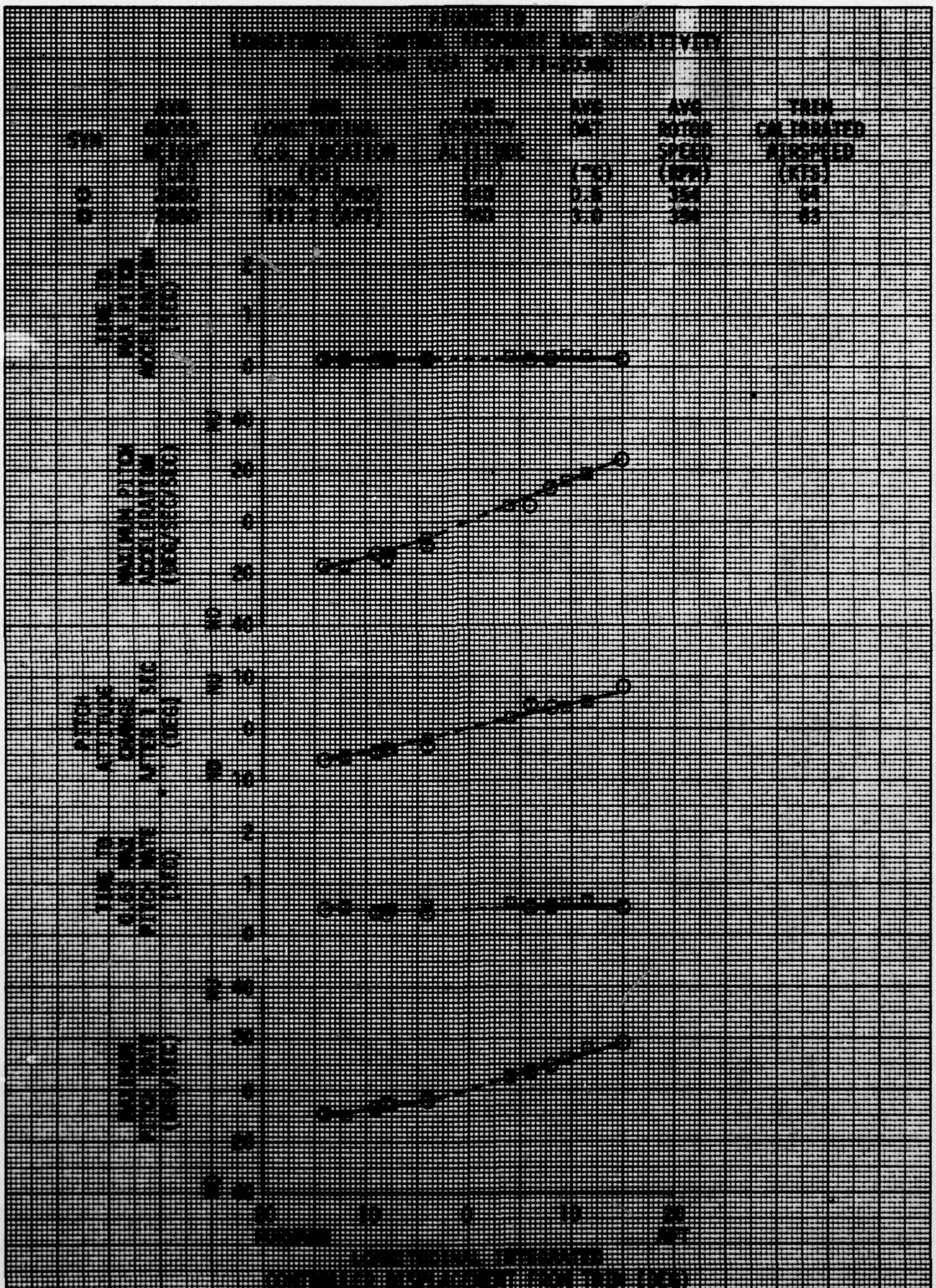


FIGURE 9
LONGITUDINAL CONTROL RESPONSE AND SENSITIVITY
OH-58A USA S/N 71-20390
HOVER





SYM
AVG GROSS WEIGHT (LB)
AVG LONGITUDINAL C.G. LOCATION (FS)
AVG DENSITY ALTITUDE (FT)
AVG OAT (°C)
AVG ROTOR SPEED (RPM)
TRIM CALIBRATED AIRSPEED (KTS)
FORWARD
AFT
LONGITUDINAL CONTROLLER DISPLACEMENT FROM TRIM (DEG)

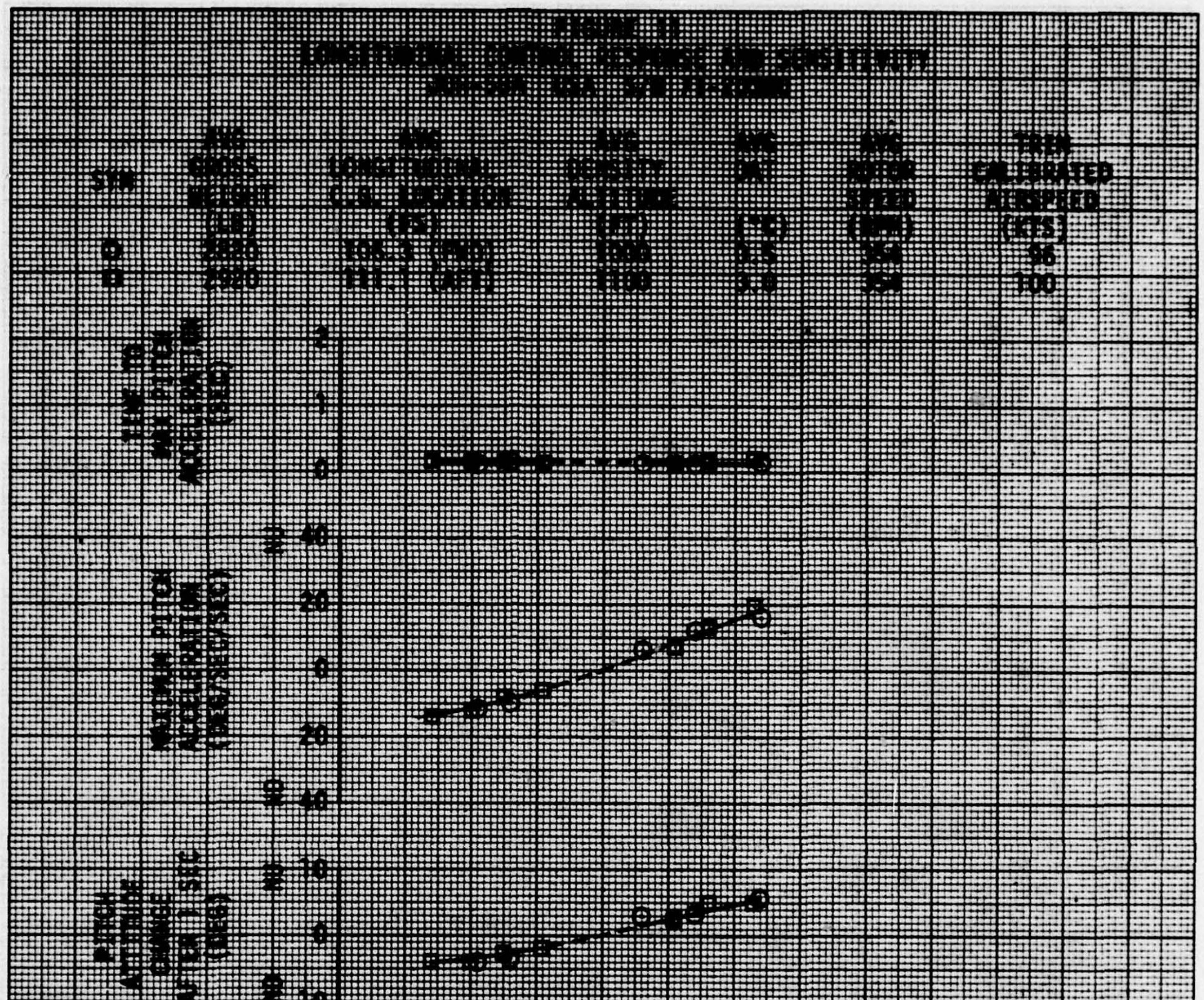


FIGURE 11
LONGITUDINAL CONTROL RESPONSE AND SENSITIVITY
SYM
AVG GROSS WEIGHT (LB)
AVG LONGITUDINAL C.G. LOCATION (FS)
AVG DENSITY ALTITUDE (FT)
AVG OAT (°C)
AVG ROTOR SPEED (RPM)
TRIM CALIBRATED AIRSPEED (KTS)
105.3 (MID)
111.1 (AFT)
TIME TO MAX PITCH ACCELERATION (SEC)
MAXIMUM PITCH ACCELERATION (DEG/SEC/SEC)
PITCH ATTITUDE CHANGE AT 1.0 SEC (DEG)
TIME TO 0.63 MAX PITCH RATE (SEC)
MAXIMUM PITCH RATE (DEG/SEC)
FORWARD
AFT
LONGITUDINAL INTEGRATED CONTROLLER DISPLACEMENT FROM TRIM

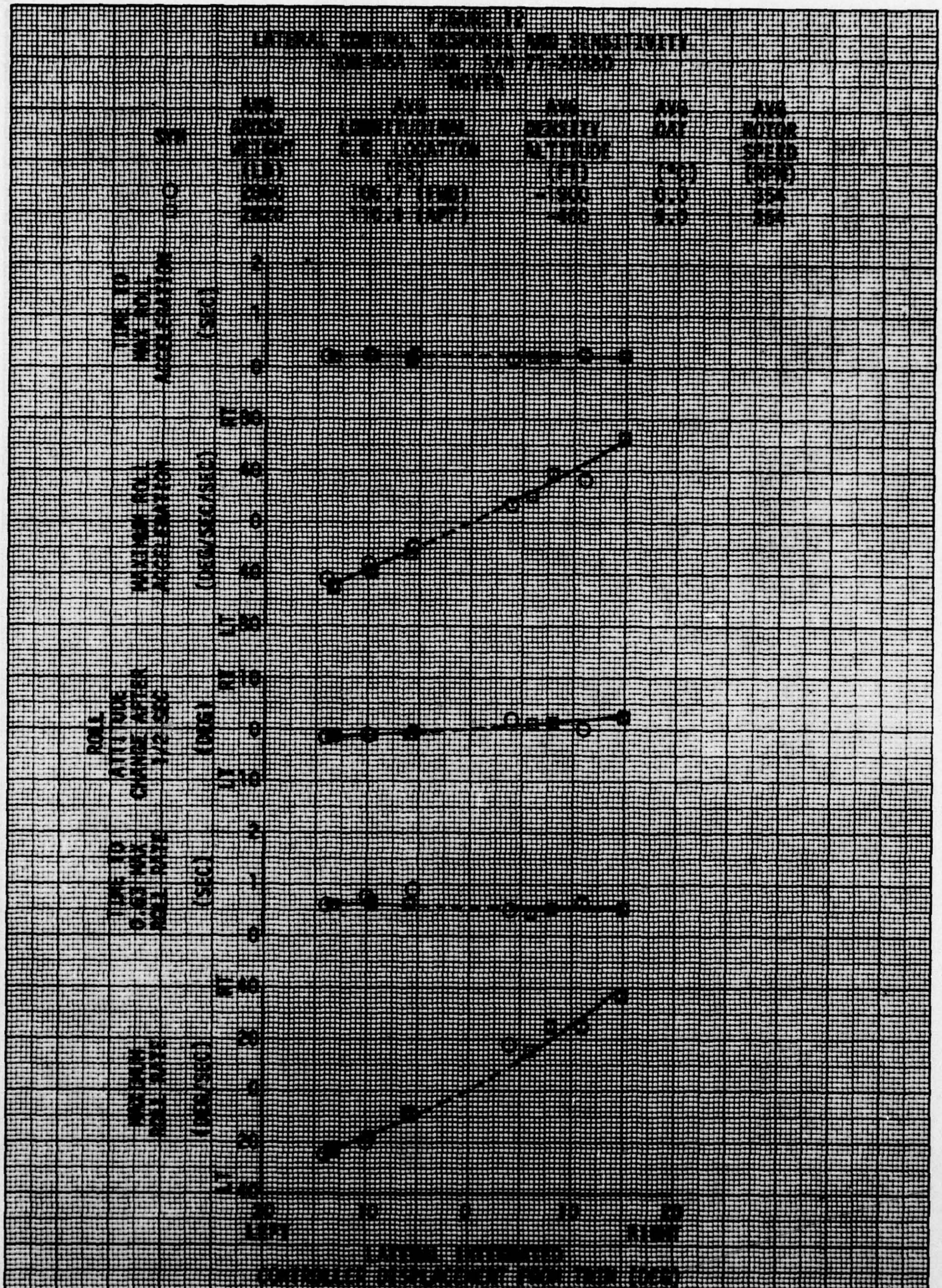
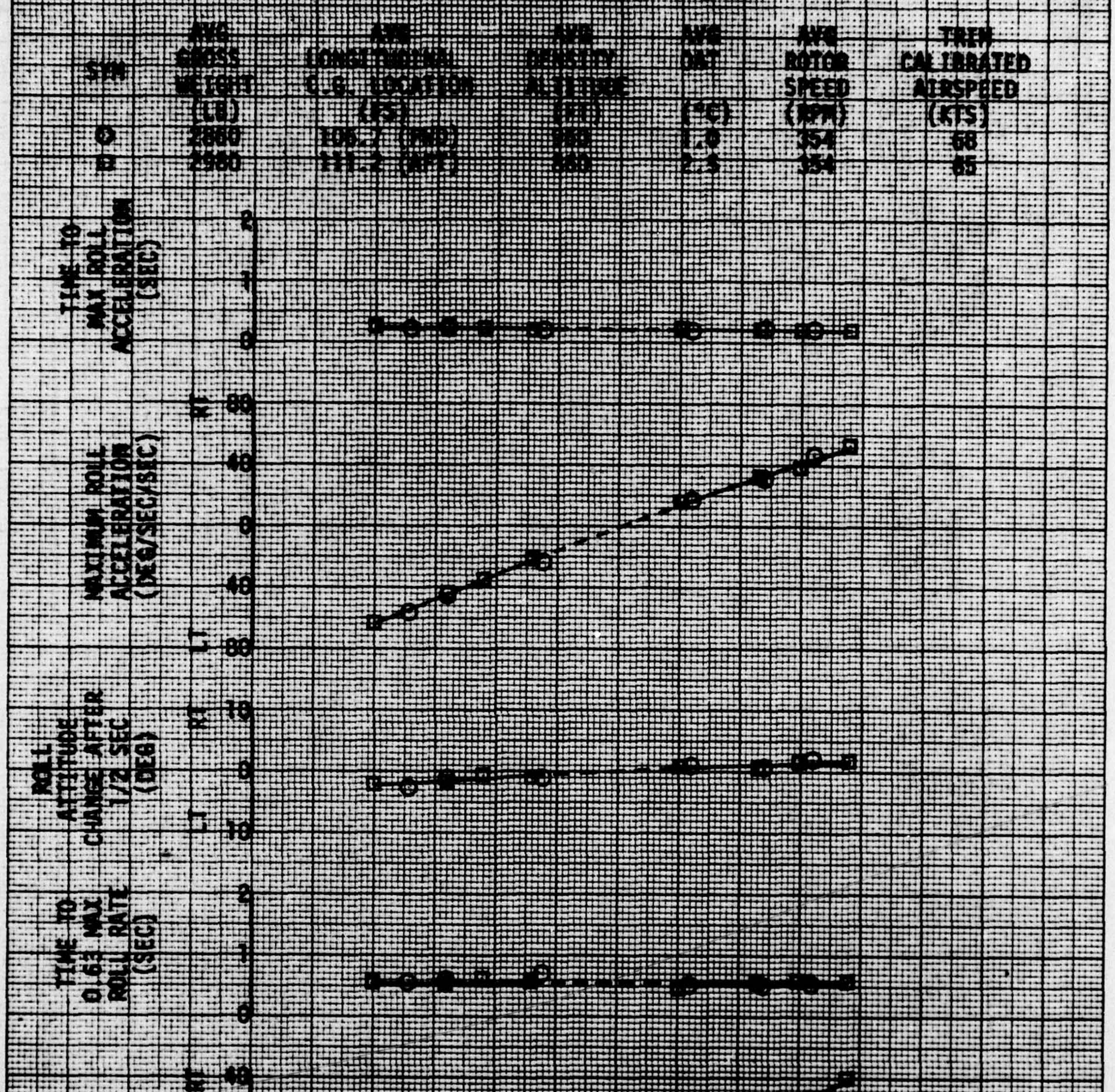
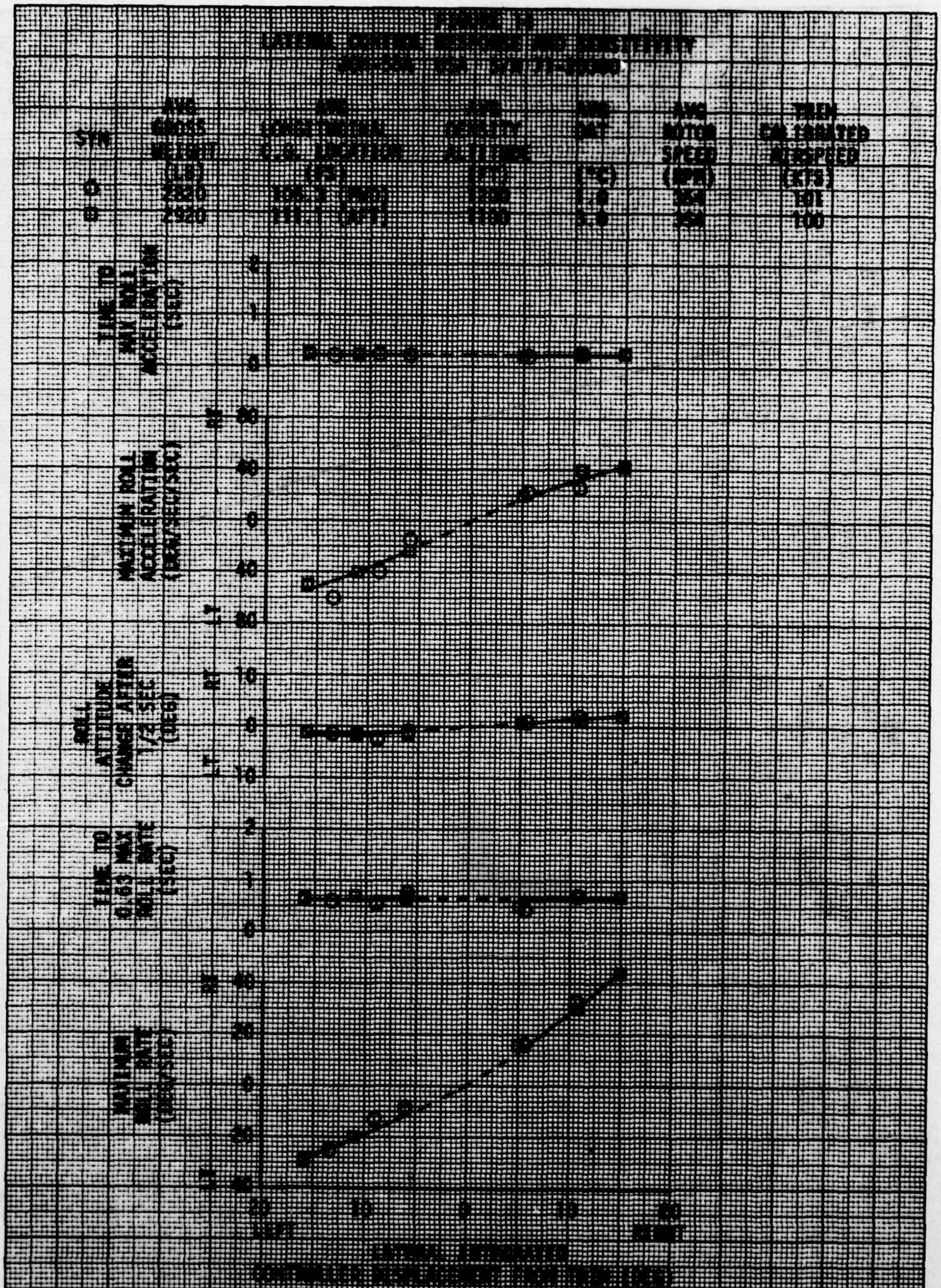

LATERAL CONTROL RESPONSE AND SENSITIVITY
SYM
AVG GROSS WEIGHT
AVG LONGITUDINAL C.G. LOCATION
AVG DENSITY ALTITUDE
AVG OAT
AVG ROTOR SPEED
MAXIMUM ROLL RATE
MAXIMUM ROLL ACCELERATION
TIME TO MAX ROLL ACCELERATION
ROLL ATTITUDE CHANGE AFTER 1/2 SEC
LEFT
RIGHT

FIGURE 13
LATERAL CONTROL RESPONSE AND SENSITIVITY



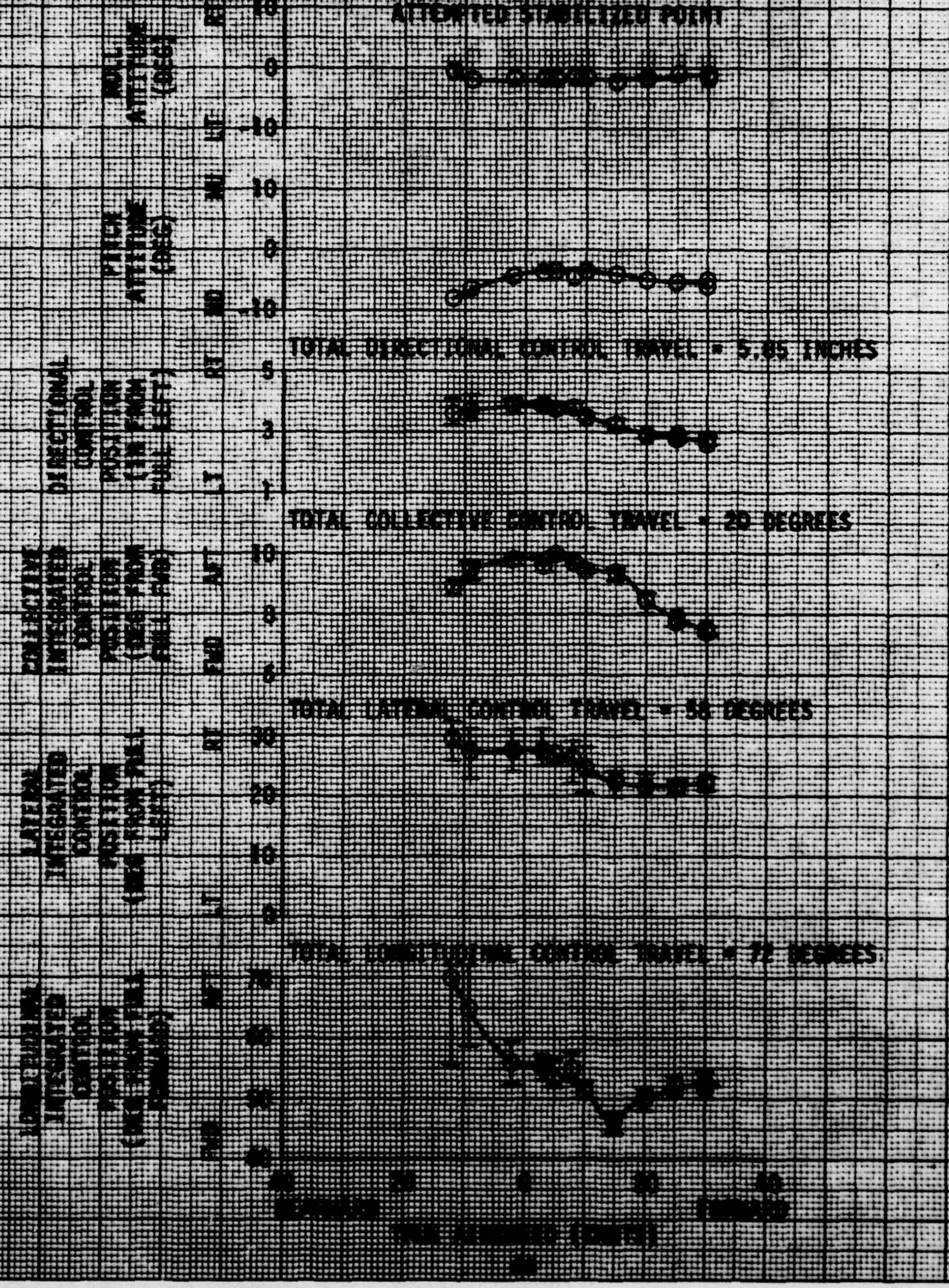


LATERAL CONTROL RESPONSE AND SENSITIVITY
SYM
AVG GROSS WEIGHT (LB)
AVG LONGITUDINAL C.G. LOCATION (FS)
AVG DENSITY ALTITUDE (FT)
AVG OAT (°C)
AVG ROTOR SPEED (RPM)
TRIM CALIBRATED AIRSPEED (KTS)
2820
2920
101
100
TIME TO MAX ROLL ACCELERATION (SEC)
MAXIMUM ROLL ACCELERATION (DEG/SEC/SEC)
ROLL ATTITUDE CHANGE AFTER 1/2 SEC (DEG)
TIME TO 0.63 MAX ROLL RATE (SEC)
MAXIMUM ROLL RATE (DEG/SEC)
LEFT
RIGHT

FIGURE 15
LOW SPEED FORWARD AND REARWARD FLIGHT
JOH-58A USA S/N 71-20380

AVG GROSS WEIGHT (LB)	AVG LONGITUDINAL C.G. LOCATION (FS)	AVG DENSITY ALTITUDE (FT)	AVG OAT (°C)	AVG ROTOR SPEED (RPM)	SKID HEIGHT (FT)
2840	106.5 (FWD)	-1240	4.0	354	15

NOTE: I DENOTES EXTREME TRAVEL FROM TRIM DURING ATTEMPTED STABILIZED POINT



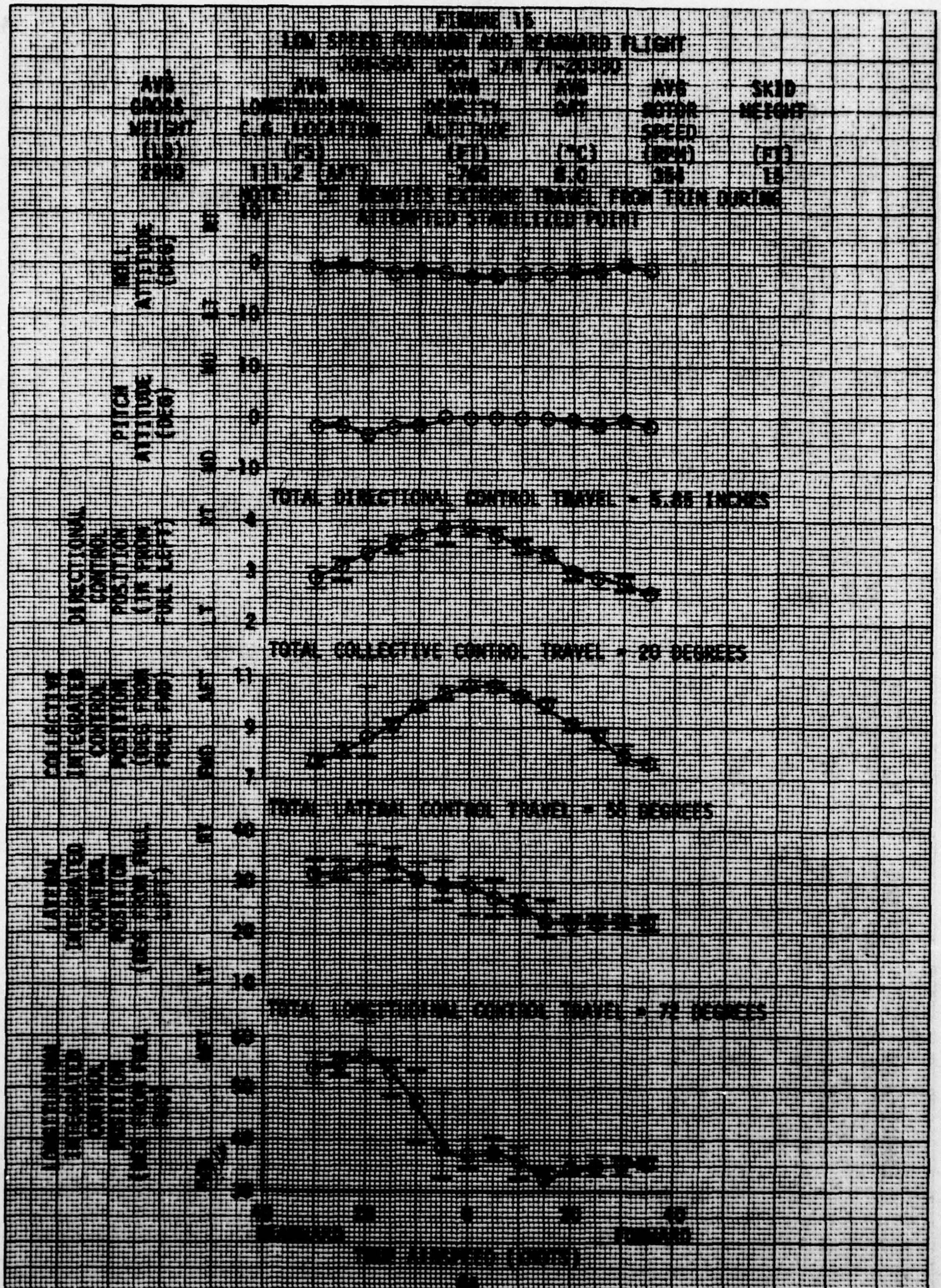


FIGURE 15
LOW SPEED FORWARD AND REARWARD FLIGHT
JOHNSON USA S/N 71-20380
AVG GROSS WEIGHT (LB) 2980
AVG LONGITUDINAL C.G. LOCATION (FS) 111.2 (AFT)
AVG DENSITY ALTITUDE (FT) 760
AVG OAT (°C) 8.0
AVG ROTOR SPEED (RPM) 384
SKID HEIGHT (FT) 15
NOTE: DENOTES EXTREME TRAVEL FROM TRIM DURING ATTEMPTED STABILIZED POINT
ROLL ATTITUDE (DEG)
PITCH ATTITUDE (DEG)
TOTAL DIRECTIONAL CONTROL TRAVEL = 5.85 INCHES
DIRECTIONAL CONTROL POSITION (IN FROM FULL LEFT)
TOTAL COLLECTIVE CONTROL TRAVEL = 20 DEGREES
COLLECTIVE INTEGRATED CONTROL POSITION (DEG FROM FULL DWN)
TOTAL LATERAL CONTROL TRAVEL = 56 DEGREES
LATERAL INTEGRATED CONTROL POSITION (DEG FROM FULL LEFT)
TOTAL LONGITUDINAL CONTROL TRAVEL = 72 DEGREES
LONGITUDINAL INTEGRATED CONTROL POSITION (DEG FROM FULL FWD)
REARWARD
FORWARD
TRUE AIRSPEED (KNOTS)

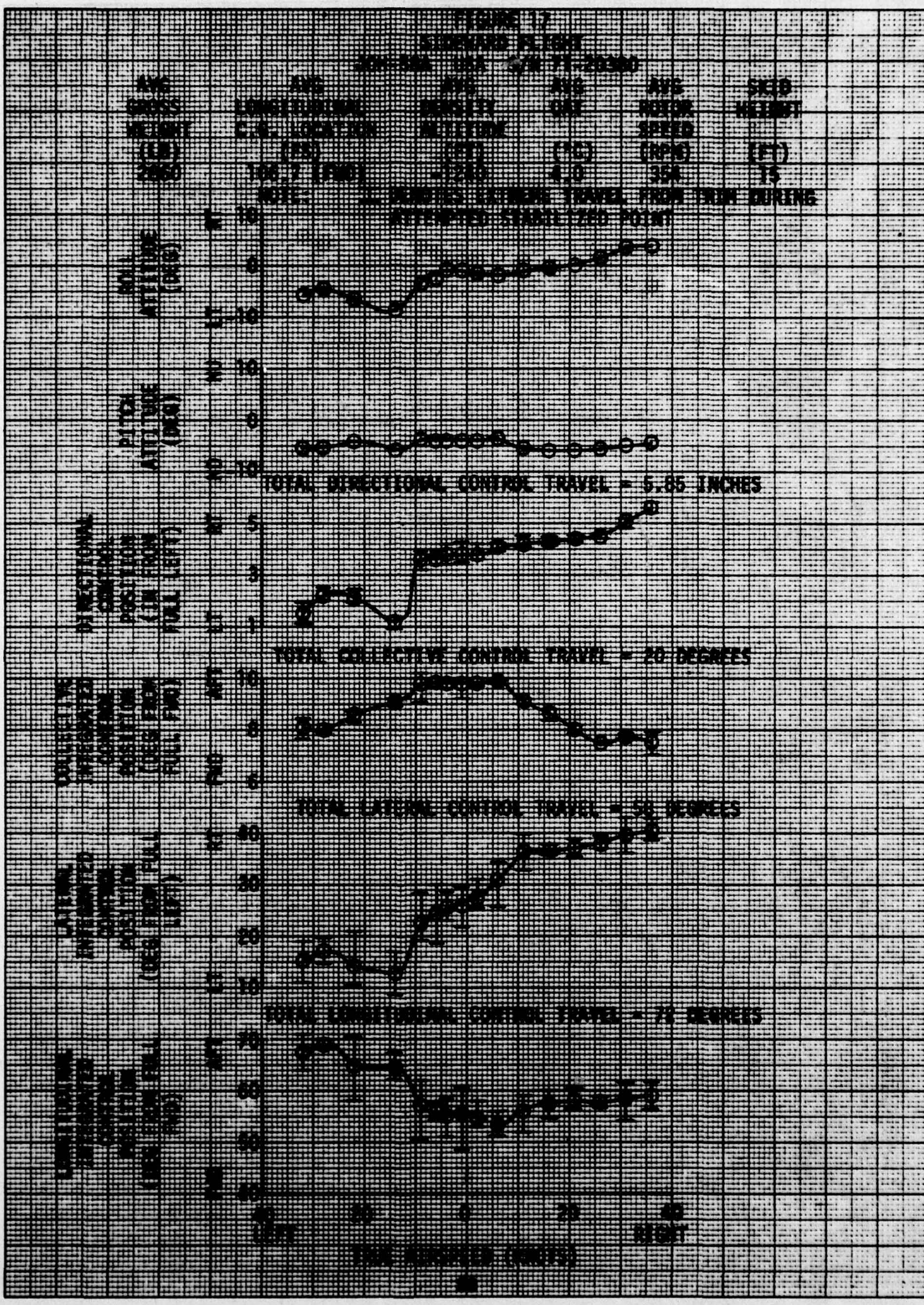
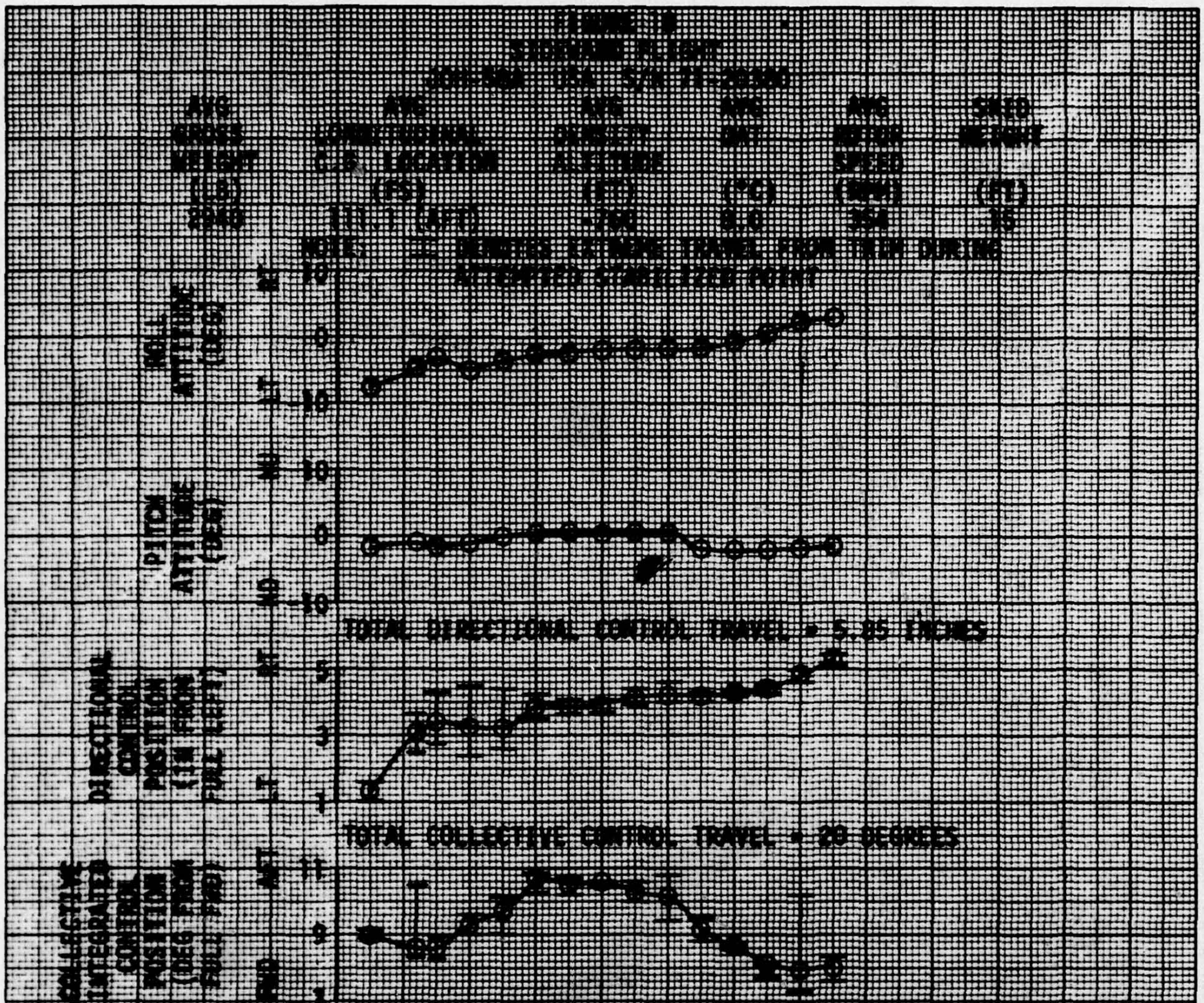


FIGURE 17
SIDEWARD FLIGHT
AVG GROSS WEIGHT (LB) 2860
AVG LONGITUDINAL C.G. LOCATION (FS) 106.7 (FWD)
AVG DENSITY ALTITUDE (FT)
AVG OAT (°C) 4.0
AVG ROTOR SPEED (RPM) 354
SKID HEIGHT (FT) 15
NOTE:
DENOTES EXTREME TRAVEL FROM TRIM DURING ATTEMPTED STABILIZED POINT
ROLL ATTITUDE (DEG)
PITCH ATTITUDE (DEG)
TOTAL DIRECTIONAL CONTROL TRAVEL = 6.85 INCHES
DIRECTIONAL CONTROL POSITION (IN FROM FULL LEFT)
TOTAL COLLECTIVE CONTROL TRAVEL = 20 DEGREES
COLLECTIVE INTEGRATED CONTROL POSITION (DEG FROM FULL DN)
TOTAL LATERAL CONTROL TRAVEL = 58 DEGREES
LATERAL INTEGRATED CONTROL POSITION (DEG FROM FULL LEFT)
TOTAL LONGITUDINAL CONTROL TRAVEL = 78 DEGREES
LONGITUDINAL INTEGRATED CONTROL POSITION (DEG FROM FULL FWD)
LEFT
RIGHT
TRUE AIRSPEED (KNOTS)


SIDEWARD FLIGHT
AVG GROSS WEIGHT (LB)
AVG LONGITUDINAL C.G. LOCATION (FS) 111.1 (AFT)
AVG DENSITY ALTITUDE (FT)
AVG OAT (°C) 8.0
AVG ROTOR SPEED (RPM) 354
SKID HEIGHT (FT) 15
ROLL ATTITUDE (DEG)
PITCH ATTITUDE (DEG)
TOTAL DIRECTIONAL CONTROL TRAVEL = 5.85 INCHES
DIRECTIONAL CONTROL POSITION (IN FROM FULL LEFT)
TOTAL COLLECTIVE CONTROL TRAVEL = 20 DEGREES
COLLECTIVE INTEGRATED CONTROL POSITION
TOTAL LATERAL CONTROL TRAVEL = 58 DEGREES
LATERAL INTEGRATED CONTROL POSITION
TOTAL LONGITUDINAL CONTROL TRAVEL = 72 DEGREES
LONGITUDINAL INTEGRATED CONTROL POSITION
LEFT
RIGHT
TRUE AIRSPEED (KNOTS)

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